THE SPECIALISTS' SERIES

TELFORD

MAGNETO- AND DYNAMO-ELECTRIC MACHINES.

MAGNETO- AND DYNAMO-ELECTRIC MACHINES.

WITH

A DESCRIPTION OF ELECTRIC ACCUMULATORS.

A PRACTICAL HANDBOOK.

Gustav

TRANSLATED FROM THE GERMAN OF GLACER DE CEW

BY F. KROHN.

SECOND EDITION, ENLARGED.

WITH A PREFACE AND AN ADDITIONAL CHAPTER ON THE LATEST TYPES OF MACHINE.

BY

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LONDON:

WHITTAKER & CO., 2, WHITE HART ST., PATERNOSTER SQUARE.

GEORGE BELL & SONS, YORK STREET, COVENT GARDEN.

1887.

LONDON:
PRINTED BY J. OGDEN AND CO.,
29, 30 AND 31, GT. SAFFRON HILL, E.C.

PREFACE.

In the preface to the second edition of this work, a fitting opportunity is presented for brief remark on progress made since the first edition appeared.

The construction of the dynamo has in recent years passed into the hands of mechanicians who, thoroughly conversant with the principles underlying the designing of machines generally, have completely remodelled it from a mechanical point of view. To this is to be attributed in no small degree, the greater capacity of modern machines as compared with the capacity of those designed but a few years ago.

Simultaneously with improvements effected in its mechanical construction, its general proportions have been influenced to an unexpected extent by a more correct apprehension of the principles upon which its action depends. From a crude appliance, mechanically and electrically imperfect, has been evolved within a period

comparatively short, a machine which as an agent for the transformation of energy must be classed amongst the most efficient.

The whole of the energy of which a machine is the recipient must reappear in some form or other, and the commercial efficiency of the dynamo is judged by the proportion directly serviceable of the reappearing energy. In modern machines the energy appearing between the terminals and available for lighting and other work reaches from 80 to 90 per cent of that given to the pulley. In machines manufactured a few years ago, the useful return rarely exceeded 60 per cent.

The increase of commercial efficiency is directly attributable to progress in two directions. First, the internal losses arising from the generation of eddy currents in the armature cores and supports have been almost eliminated; secondly, the electrical energy expended in forcing the current through the armature and in exciting the magnets has been reduced to a very small amount.

Progress in the first direction has been achieved by giving special attention to the method by which the armature is attached to the spindle and by properly laminating its iron core. As a result of successive improvements, the combined losses arising from eddy currents, and from friction of bearings and collector brushes have been reduced in ordinary working to about 5 per cent of the power given to the driving pulley, the conversion efficiency thus reaching 95 per cent.

In the second direction progress has been made by

putting into the field magnets and armature cores more iron than it was formerly the practice to employ, the double result being a stronger magnetic field created by the expenditure of a smaller amount of energy and an armature of low resistance in which the electrical waste is less. In modern machines there appears between the terminals from ·9 to ·95 of the energy converted. In other words the electrical efficiency varies from 90 to 95 per cent.

Although this step by step progression is due to the accumulated labours of many workers in many fields, yet taking a prominent position amongst the factors which have influenced it, is the recognition that the path which the lines of force take in a machine form a closed circuit, the magnetic resistance of which ought to be as small as possible. The magnetic field is proportional to the excitement supplied in ampère-turns divided by the combined resistance of the field magnets, armature core and air-space which together make up the complete circuit. The resistance of each of these parts is separately found by dividing its length measured in the direction of the lines of force by its cross section and multiplying by a coefficient which in the case of the magnet and armature core has a value depending on the degree of saturation employed. These coefficients are easily obtained from experiment and as a consequence the behaviour of dynamos can be predicted previous to their construction with close approximation to accuracy.

The cross section of the armature core determines the number of lines of force which can be enclosed by the

rotating coils, and hence the e.m.f., which can be produced. The latter is quite independent of the shape of the core or of the extent of the polar surfaces, but on the other hand with an extended surface the field is produced by a smaller exciting current due to diminished magnetic resistance. If the armature core is too small, a great number of force lines leak from pole to pole without going through the coils, and energy is consequently wasted in creating a field which cannot be utilised. That uniformity of opinion concerning the best ratio of the cross section of the armature to that of the magnet has not yet been reached, is evident from the fact that in modern machines this ratio varies from ·5 to 1·0.

Given a machine having an armature core of definite cross section and the efficiency, so far as the armature is concerned, can be increased by making the lines of force in the core more dense, since then a greater number is enclosed by a given length of wire. Although the density is always greater in machines having armature cores relatively small, a high degree of saturation in the armature means a proportionally increased leakage across the poles. Bearing this in mind, it is not unlikely that the best result will be secured by making the cross section of the iron in the magnetic circuit uniform throughout, even if the armature core is thereby saturated to a less degree.

The exact process by which modern dynamos have been made electrically more efficient, will be readily comprehended. The e.m.f. produced at a given speed depends, other things being equal, on the product of the

armature core area into the number of convolutions. The energy wasted in the armature depends on the number of convolutions. By reducing the latter factor of the product and increasing the former, or, in other words by diminishing the copper and increasing the iron, the energy expended in the armature has been reduced to a very small quantity. But a diminished quantity of copper on the armature means a diminished air-space, and from this, combined with the increased masses of iron in the fields and armature, has resulted a magnetic circuit of low resistance in magnetising which there is expended an amount of energy comparatively small.

In the present edition of the work the writer has undertaken the task of describing the latest types of machine; but it will be found that, in several particulars, those of the best makers differ from each other. This is explained on the grounds that the object sought to be obtained is different in different cases, and designs will continue to be modified to suit circumstances and in accordance with the conditions under which the machines have to work. At the present time we find the same manufacturers constructing machines of widely differing types to suit requirements as widely differing. Descriptions of the latest of these will be found in Chapter XII., and it is hoped that the work has been rendered more valuable by leaving the original translation intact with the descriptions of the older forms untouched, inasmuch as there is thereby afforded a direct comparison between machines old and new. The student is asked to read this chapter in conjunction with the original text when he will

be able to see more clearly the direction of recent progress.

In conclusion the writer has to thank Messrs. Mather and Platt, R. E. Crompton and Co., Paterson and Cooper, W. H. Allen and Co., Chamberlain and Hookham, The Anglo-American Brush Electric Light Corporation, The Elwell Parker Co., and The Gülcher Electric Light Co. for the illustrations and descriptions of their machines, and the proprietors of "The Electrical Review," "The Electrician," and "Industries" for the use of several illustrations.

W. B. ESSON.

LONDON, *January*, 1887.

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PRACTICAL UNITS.

I. Mechanical Units :—

Unit of Time	=	One Minute.
Unit of Space	=	One Foot.
Unit of Force	=	The Force which will support a weight of one pound.
Unit of Work	=	One foot-pound = a force of one pound exerted through one foot.
Unit of Power	=	The horse-power = 33,000 foot-pounds per minute.

II. Electrical Units :—

Unit of Current	=	The Ampère.
Unit of Quantity	=	The Coulomb = the quantity of Electricity passing in one second if the current is one Ampère.
Unit of E. M. F.	=	The Volt = a little less than the e.m.f. of a Daniell's cell.
Unit of Work	=	The Joule = one Coulomb at an e.m.f. of one volt (sometimes called the volt-coulomb).
Unit of Power	=	The Watt or volt-ampère = 60 Joules per minute.
Unit of Resistance	=	The ohm = a resistance such that a current of one Ampère flows due to an e.m.f. of one volt = the resistance offered by a column of mercury 106 centimetres in length by one square millimetre section.

III. Electro-Mechanical Equivalents :—

One horse-power	=	746 Watts.
One watt	=	44·236 foot-pounds per minute.
One foot-pound	=	1·356 Joules.
One Joule	=	·73726 foot-pounds.

IV. Unit of Output of Generators = 1,000 Watts.

INTRODUCTION.

HISTORICAL DEVELOPMENT OF MAGNETO-ELECTRIC AND DYNAMO-ELECTRIC MACHINES.

So long as only galvanic batteries were employed in practice for generating electric currents, that is, so long as these currents were obtained solely by chemical action, it was but natural that, for doing large quantities of work, the application of electrical energy should be very limited For the cost of maintaining a battery is too high as compared with its efficiency, and it is almost impossible to obtain in this way constant currents of great quantity and intensity. A larger field for the application of electrical energy was opened up when use began to be made of electric currents, produced by the conversion of mechanical energy, through the invention of electric machines.

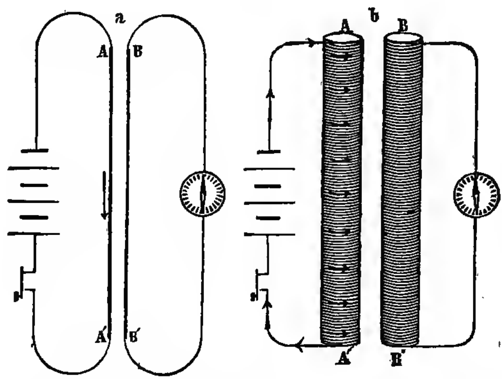
Faraday's researches on the phenomena of induction, formed the theoretical basis for the construction of electric machines.

He had shown that when a current circulates in a wire, $A\ A'$, Fig. 1, a, forming part of a circuit, momentary currents will under certain circumstances be induced in a neighbouring wire, $B\ B'$, parallel to the first. These

currents will flow in the direction of the primary current, $A\ A'$, or in an opposite direction, according to circumstances; and this direction can easily be observed by the deflections of the needle of a galvanometer connected with the wire $B\ B'$.

A current in a direction opposite to that of the primary current, that is in a direction from B' to B, will be generated: (1) at the moment when the primary current

Fig. 1.



is started; (2) when the wires $A\ A'$ and $B\ B'$ are approached to each other; and (3) when the current in $A\ A'$ is strengthened.

A current is set up in the same direction as that of the primary current, that is from B to B': (1) at the moment when the current in $A\ A'$ is interrupted; (2) when the wires $A\ A'$ and $B\ B'$ are moved away from each other; (3) when the current in $A\ A'$ is weakened.

The discovery of the currents generated on the approach of the wires to each other (approximation currents), and on their being moved away from each other (retrocession

currents), was of special importance for the construction of electric machines.

Far stronger induction currents are generated if the primary wire, as well as the wire in which currents are to be induced (the secondary wire) are coiled into spirals, or helices, and if both are so placed that the separate turns of the one can act on those of the other, as shown, for example, in Fig. 1, *b*. In this case, the strength of the induced current $B\ B'$ increases, generally with the number of turns or convolutions in the two wires; for under the conditions assumed, small currents are induced by each turn of the primary wire $A\ A'$, in every neighbouring turn of the secondary wire $B\ B'$, and these unite to form a total strong current.

The practical importance of this fact is only fully learned from the results of investigations by Ampère, who discovered that a magnet may be considered to be a piece of iron perpetually encircled by parallel electric currents, and that by approaching a magnet to a conducting wire or by moving the magnet away, currents can be induced in the wire, in the same way as if there were used a wire spiral through which a current is flowing.

It is to Pixii that the honour is due of having made the first practical application of this discovery. He constructed the first magneto-electric machine in 1832. The mode of action of this machine, illustrated in Fig. 2, will be made clear from what follows.

According to Ampère every magnet is encircled by parallel electric currents in such a way that if the north pole is pointed towards the observer, they circle in a direction opposite to that of the hands of a clock, whilst, if the observer faces the south pole, the currents flow in the direction of the hands of a clock.

In Pixii's machine, Fig. 2, there is a compound horse-shoe magnet which can revolve on its axis, and above the poles of this magnet is fixed the armature. This consists of two wire coils, whose convolutions form a continuous helix. These coils contain two soft iron cores, which at every approach of the poles of the magnet are themselves converted into magnets.

Fig. 2.

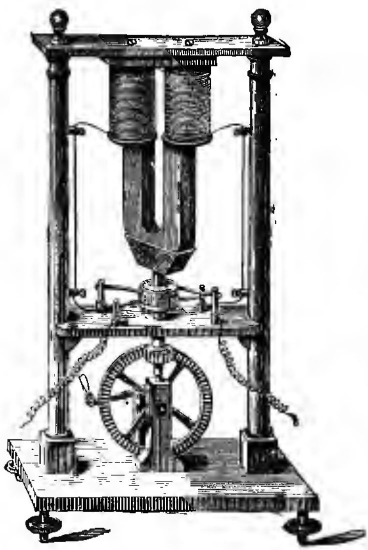


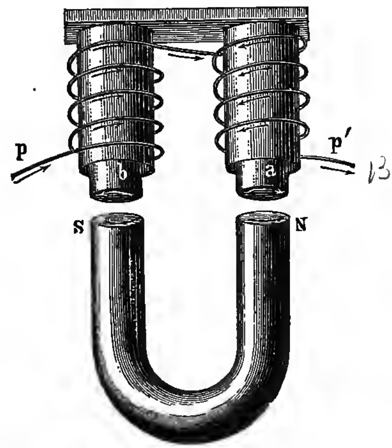
Fig. 3 shows more clearly in what way the coils of wire are wound, and this figure serves better for explanation. Whenever the pole N of the magnet approaches the soft iron core a of one of the coils, a will become a south pole, for a magnet always magnetises a piece of iron close to (but not touching) it in such a way that a south pole is induced opposite the north pole, and a north pole opposite the south pole. At the same time, according to Ampère's law, electric currents will be generated, and these will then circulate round the iron core of the coil in the direction of the hands of a clock. But as soon as these currents are started, they will induce others in the turns of the wire coil, which are seen in the figure to flow from right to left.

Simultaneously, however, b will become a north-pole on account of the pole S approaching it, and Ampèrian

currents will commence encircling the iron core of the second coil from right to left. The moment these are started, they induce currents in the coils surrounding the iron core, which flow in the direction of the hands of a clock.

A careful examination of Fig. 3 will show that the two currents simultaneously generated in the two coils, though seeming to flow in opposite directions, really form one current in the wire system, as indicated by the arrows. This current traverses the wire system in the same direction, from p to p', and can be conducted away by the terminal wires p and p'. An opposite current, one from p' to p, is induced in the wire system of the coils as soon as the poles of the magnet, N S, begin to move away from the iron cores a and b, in continuing their revolution. For the resulting gradual demagnetisation of the iron cores causes a weakening of the Ampèrian currents encircling them, and, according to Ampère's law, this weakening must induce currents in the surrounding turns of wire of the opposite direction.

Fig 3.



Finally, the poles of the magnet will again approach the iron cores, in such a way that N approaches b, and S approaches a, and since a now becomes a north-pole and b a south-pole, a current will be induced in the wire coils

opposite in direction to the original current of approach, but which is only a continuation of the current produced by the preceding demagnetisation of the iron cores. All this the reader will easily perceive if he makes an analysis of the separate processes. After the second current of approach follows a retrocession current, and so on. From what has been said, it will be seen that in every complete revolution of the magnet *N S* round its axis, the current in the turns of the wire coils changes its direction twice, the changes taking place at the moments when the poles *N S* pass the ends of the iron cores.

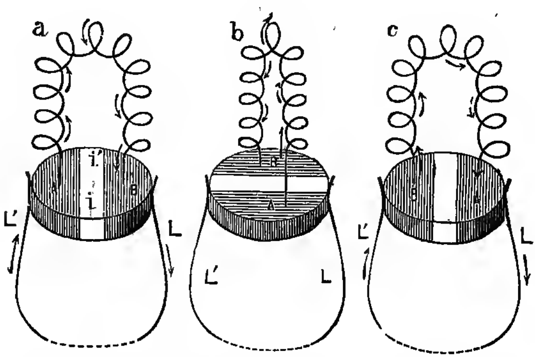
In order to convert the two opposite currents, generated during each complete revolution of the magnet *N S*, into a current of single direction, where this is desirable, a commutator is added to the machine. Fig. 4 shows the principle on which it is constructed.

One end of the conducting wire of the armature coil is connected with the metallic segment *A*, Fig. 4, *a*; the other end of the wire is connected with segment *B*. The segments are separated from each other by a strip of insulating material, *i i*, and the commutator is fixed in such a way that it revolves once round its axis simultaneously with the magnet (or simultaneously with the armature in the machines to be subsequently described).

Now, if the induction current be supposed to flow through the turns of the helix, in the direction from *A* to *B*, when the pole *N* approaches *a*, and the pole *S* approaches *b*, it is clear that it will flow in the direction from *L* to *L'* in the conducting wire *L L'*, whose terminals bear on the metallic segments. When the poles *N* and *S* recede from *a* and *b*, and the retrocession current is started, the current in the spiral changes its direction, and now

traverses the latter from *B* to *A*. In order to avoid a change of current in the conducting wires, the commutator is arranged so that at the moment when there occurs the change of current, and when the helix is momentarily currentless, the conducting wires *L L′* bear on the insulating portion of the commutator, Fig. 4 *b*. Simultaneously with the commencement of the new current, *L* bears on *A*, and *L′* on *B*; consequently, although the current in the spiral of the armature flows from *B* to

Fig. 4.



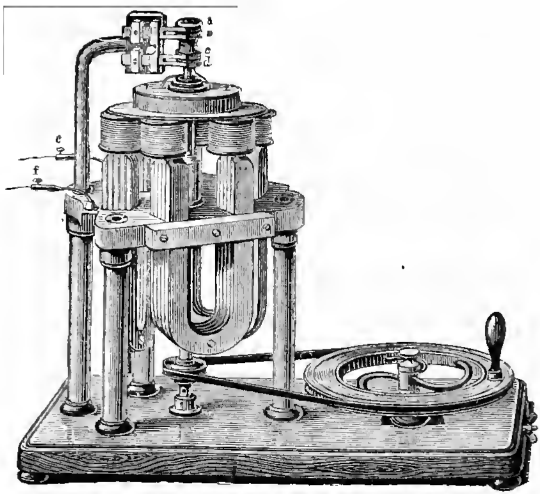
A, it will continue to flow in the original direction in the conducting wires, that is, from *L* to *L′*. Thus the two opposite currents, generated during each complete revolution of the magnet, are made to flow in the same direction in the external circuit by means of the commutator.

Pixii's machine had this practical disadvantage, that the heavy compound magnet rotated in front of the armature. Subsequent constructors, as Saxton, Clarke, and others, modified the machine, making the lighter armature rotate in front of the magnet. Besides this, Saxton placed the magnet as well as the bobbins of the armature in a hori-

zontal position, whilst Clarke retained the vertical position of the magnet, but placed it with the poles downwards, and made the bobbins of the armature rotate at its side. It seems also, that Saxton was the first to employ the commutator previously described.

Stöhrer considerably increased the efficiency of magneto-

Fig. 5.



electric machines by increasing the number of the magnets as well as the number of armature-bobbins.

In this machine six armature-bobbins rotate before the six poles of three compound magnets. The coils of the bobbins are wound in such a way that at each approach of the coils to the magnet poles currents flowing in the same direction are generated, and these unite to form one current; again, every time the bobbins of the armature recede from the poles of the magnets, currents are induced

which flow in the coils in a direction opposite to that of the currents of approach. Accordingly, in each complete revolution of the armature six compounded currents of approach, and six compounded currents of retrocession are generated in the wire coils of the armature-bobbins, and each of these, again, is composed of six elementary currents. By means of a commutator, connected with the machine, these alternating currents can be rectified before reaching the external circuit.

The results obtained with Stöhrer's machine were so satisfactory that subsequent inventors, adopting his idea, continued to increase the number of the armature-bobbins and magnet-poles, and in this way succeeded in obtaining currents of remarkable strength, following each other in rapid succession. Thus, by degrees, were developed the large magneto-electric machines for alternating currents, such as those of the "Alliance Company" constructed by Nollet, and the machines of Holmes, Lontin and others, which, side by side with the machines for continuous currents, are still, under certain circumstances, used in practice, especially for the electric light in lighthouses. All these machines, which in principle are only enlarged Pixii machines, will be dealt with in the chapter on "Machines generating alternating currents."

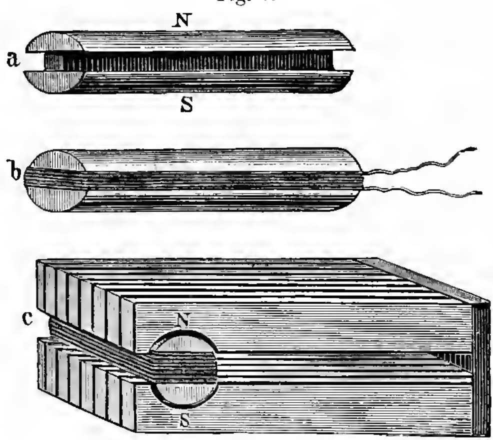
A notable modification in the construction of magneto-electric generators was made by Dr. Werner Siemens, of Berlin, in 1857, who greatly improved the shape of the armature-bobbins.

Experiment soon showed that the strength of the currents produced by a magneto-electric generator is increased when the coils of the armature are brought as near as possible to the magnetic poles; and that the efficiency of a machine depends further on the interruption

being as short as possible when the current changes its direction. Siemens took both these experimental laws into account in the construction of his armature, the simplest form of which is represented in Fig. 6.

An iron cylinder, *a b*, Fig. 6 *a*, is provided with two grooves, and the spirals of the conducting wire are wound round this cylinder, parallel with its axis, in such a way that the two grooves are filled up, the complete cylindrical

Fig. 6.



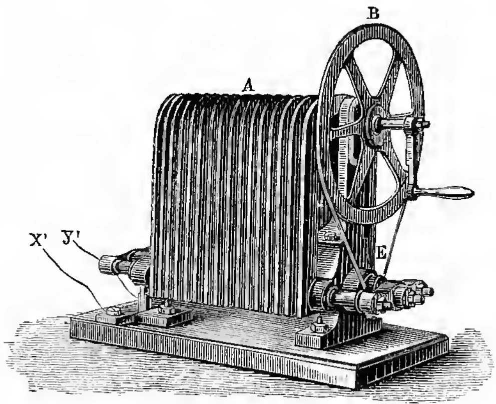
form being thus restored, Fig. 6 *b*. One of the terminal wires is connected with the shaft of the armature, whilst the other is connected with a ring which is insulated from the shaft. Two springs, one of which bears on the insulated ring, and the other on the shaft, conduct the currents to the external circuit.

In Fig. 7, a small Siemens machine is illustrated, and from this figure can be seen the position that the rotating cylinder takes up between the poles of the magnets. The magnets are usually numerous. The poles of the magnets,

Fig. 6 *c*, have semi-circular pieces cut out, so that the cylinder is well-surrounded; in fact in the whole construction of Siemens' machine, the inductive action of the permanent magnets is far more completely utilised than in the magneto-electric generators previously described.

One special advantage in the form of the cylindrical armature is that not only is the armature magnetised as completely as possible, but the poles of the steel magnets

Fig. 7.



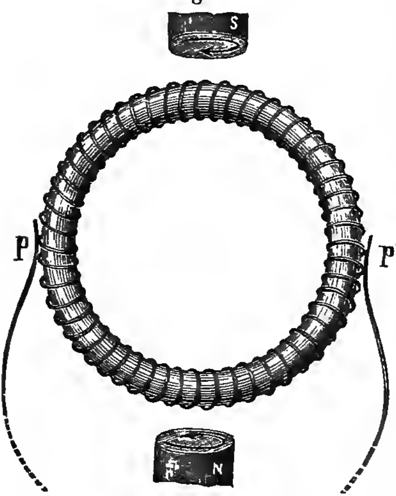
can also directly exert a strong inducing action on the spirals of the wire coils, and this considerably strengthens the currents induced by the magnetism of the soft iron core. Besides, in the cylindrical armature the time during which the current is interrupted is reduced to a minimum, as the change of poles takes place in an extremely short interval of time, when the cylinder is rotated rapidly; and this circumstance greatly increases the efficiency of the machine.

The form of cylindrical armature just described (proba-

bly now used in Siemens' alarm bell indicator only), was later on considerably modified, and so much improved that cylindrical armatures still very successfully hold their position, and have not been supplanted by the "ring" armature, which we now proceed to describe.

The ring armature, which caused quite a revolution in the construction of electric generators, was invented by Dr. Antonio Pacinotti, of Florence, in 1860, and by its means he succeeded, for the first time, in obtaining, with an electric machine, continuous electric currents flowing in a constant direction, without making use of a commutator. As Pacinotti's ring armature is to be found in principle in all machines constructed on the "Gramme" system, and as the principle of its construction is employed in almost all continuous-current machines, a careful analysis of its action will be necessary.

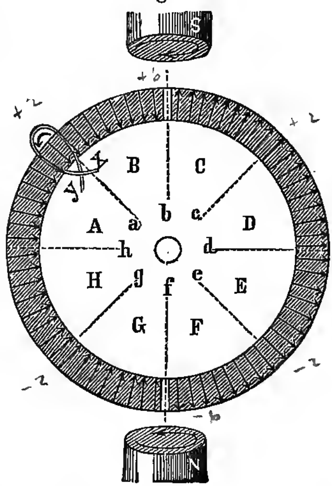
Fig. 8.



When a ring of soft-iron, Fig. 8, is placed between two magnetic poles, *N S*, a south pole will be induced opposite the north pole *N*, and a north pole opposite the south pole. Now, if the iron ring is caused to revolve round its centre from right to left, new portions of the ring will in turn be magnetised, whilst the portions of

the ring previously magnetised will lose their magnetism. Accordingly, the poles of the iron will travel along the ring from left to right. If this ring, as shown in Fig. 8, be encircled by a continuous coil of copper wire, insulated from the iron ring, currents will be induced in the wire, and the direction will be different in the several turns of the coil, accordingly as these are nearing the north pole or the south pole of the iron ring; moreover, as the poles of the ring change, in consequence of its rotation, the currents also in the convolutions of wire surrounding it will change their direction. To understand better what takes place during the revolution of the ring, it may be considered that the ring is fixed. For, in any case, its poles will always lie in the line N S, and it can be assumed that the windings of the coil move from left to right round the ring, and thus are brought under the maximum inducing action of the poles N and S. For the sake of simplicity, the inducing effect on a single turn of the coil need only be considered, and it may be supposed that the ring is divided in two, so that two north poles meet opposite S, and two south poles opposite N.

Fig. 9.



In this case, Ampèrian currents will circle round the ring, as indicated by the arrows in Fig. 9. Let us com-

mence our observation at the moment when the turn $x\ y$ is at the point where the dotted line h cuts the ring, and when it commences to move from left to right. Considering only the nearest portions of the ring, we see that the turn or loop approaches the divisions A and B, receding at the same time from divisions G and H. Now let us call the current + when its direction is from the circumference towards the centre of the ring; and — when its direction is from the centre towards the circumference. Let us also denote the current induced in the loop by the two adjoining segments of the ring by + 2 or — 2, and that induced by the portions of the ring which are more than 45° away by + 1 or — 1. We shall then be able to express the current induced in the loop at the moment when it commences to move from h towards the right by the sum of the factors $+ 1 + 2 - 2 - 1$, *i.e.*, by 0; for a current of retreat will be induced in the loop $x\ y$ by its moving away from the segments of the ring G and H, and, according to the law of induction, this current will flow in the same direction as the Ampèrian currents in the iron ring. On the other hand, by its approach to the segments A and B, a current will be induced in the loop, traversing the latter in a direction opposite to that of the Ampèrian currents in these portions of the ring. Accordingly the two currents will neutralise each other at the moment when the loop quits h, for they will be of equal strength.

If the loop has arrived at the point a, and commences its further course round the ring, it will be possible to express the current of approximation induced in it by the segments B and C, together with the current of retrocession induced by the segments H and A as the sum of the following factors, $+ 1 + 2 - 2 + 1 = + 2$. When the loop $x\ y$ leaves b, the sum equals $+ 1 + 2 + 2 + 1$,

that is, $= + 6$. On quitting c, the induced current can be represented by $+ 1 - 2 + 2 + 1 = + 2$, and again, when the loop has passed d, we can express the action by the sum of the factors $-1 - 2 + 2 + 1$, that is, by 0, and the loop has, therefore, no current induced in it.

Now, when the loop reaches the point e and continues to move towards that portion of the ring which is most strongly influenced by the north pole N, the current induced in it after it leaves e will be expressed by the sum of the factors $- 1 - 2 + 2 - 1$, that is, by $- 2$, the current, therefore, has changed its previous direction. At f the current, which is now flowing in a new direction, will reach its maximum, and be equal to $- 6$; at g its strength will again have fallen to $- 2$; and after the strength at h has sunk to 0, a change of current will again take place, and the expressions for the strength of the induction currents will have the sign $+$ prefixed.

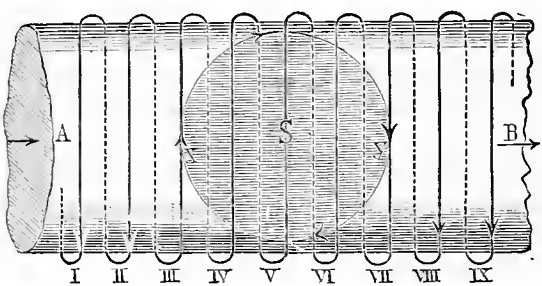
What we have said of the one turn $x\ y$ of the coil, of course equally applies to turns or groups of turns which come into the respective positions; and from the preceding considerations we see that the whole wire system which surrounds the ring can be regarded as being traversed by two opposite total currents meeting at p and p', Fig. 8. Besides, according to the explanation, we shall be able to denote that current by $+$, which is compounded of all the separate currents in the turns which surround the portion $A\ B\ C\ D$ of the ring, whilst the other current, which is compounded of the currents traversing the turns surrounding the section $E\ F\ G\ H$ of the ring may be distinguised by the prefix $-$. The rotation of the ring only so far changes the condition of things that new turns and groups of wires constantly come into the regions where the two

opposite currents dominate, and accordingly in every complete revolution of the ring, each turn passes both the neutral points once.

What has been said, however, refers only to the inducing action that the magnetised iron ring exerts on the wire coils surrounding it; all that we have now to do is to analyse the action of the fixed poles *S* and *N*, Fig. 8, on the wire system rotating between them.

We shall retain the position of the poles as shown in Fig. 8.

Fig. 10.



In this position the turns of the coils are perpendicular to the plane of cross-section of the poles when they pass the latter.

Fig. 10 will serve best for an explanation. In this *A B* represents a portion of the rotating ring, the turns of wire on which have been assumed to be moved a little asunder, though in reality they are very close together. *S* indicates the south pole, which in the figure is supposed to be under the ring. The arrows indicate the direction in which the Ampèrian currents encircle the ring. We will suppose the ring to be moving in the direction from *A* to *B*, and will only consider those portions of the coils that

are on the outside of the ring, and indicated by full lines in the figure; the portions on the inside of the ring are indicated by dotted lines, and are omitted from consideration for the present. We then perceive that in turns I. and II., currents of approach will be generated, having a direction opposite to that of the Ampèrian currents at x (from top to bottom in the figure), whilst in the turns VIII. and IX., currents of retrocession will be generated (also flowing from top to bottom in the figure) that are due to the direction of the Ampèrian currents at y, from which they are moving away.

In other words, currents of the same direction are induced in all the turns, left and right of the south pole, and this direction is exactly the same as that of the currents induced by the magnetism of the iron ring.

Now, if we take those portions of the turns into consideration that lie on the inner side of the ring, which are indicated by the dotted lines, we see that, if the iron core of the coils were not present, the south pole, S, would induce currents which would also flow from top to bottom in the figure. Accordingly, the currents induced in the internal and external portions of the turns would oppose each other; and if the portions of the turns on the inside of the ring were as close to the pole of the magnet as the portions lying on the outside, the induced currents in the inner portions would be equally as strong, and would destroy the others. This, however, is not the case, for, firstly, the portions of the turns which are on the inside of the ring are farther away from the pole S than the portions on the outside, and the currents induced in the latter would, therefore, in any case, have the greater power, even if the iron core were not present; secondly, the iron ring really does separate the inside portions of the turns

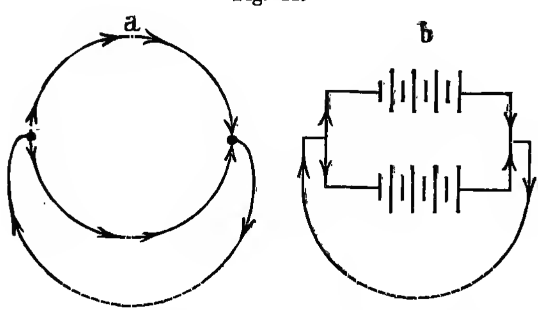
from the magnet, and completely annuls the action of the magnet on those portions, so that the currents generated in the parts of the turns lying on the outside of the ring act unopposed. As these currents flow in exactly the same direction as those induced by the magnetised iron ring, they considerably strengthen its action.

In our explanation we have, however, only spoken of the turns lying right and left of the pole, and we have not considered the turns III., IV., V., VI. and VII. The action of the pole S on these turns is equal to zero, as can be seen from what follows.

The current induced in turn IV. will principally be a retrocession current from x, and it will accordingly flow in the direction of the Ampèrian current at x. In turn VI. a current of approach will predominate, and this will flow in the same direction as the previous one, because its direction must be opposite to that of the Ampèrian current at y. The receding from x and the approach to y will exert an equally powerful influence on turn V—that is, a current of double strength will be generated in it, flowing in the same direction as the currents in IV. and VI. Now, if all the turns are the same distance apart from each other, which is the case in the figure and in reality, the opposite currents in II. and IV. will have the same strength, and will neutralise each other, and a change of current will take place in turn III., for which reason this turn will be currentless. Similarly, there will be no current in turn VII., on account of the currents in VI. and VIII., which neutralise each other; and as currents I. and IX. are equidistant from V., the double current in V. will be annulled by currents I. and IX., which are opposite in direction to it; all the turns from III. to VII. will accordingly be currentless. As a result, therefore,

we only obtain the currents generated in the turns right and left of the south pole, and this, as we have observed, strengthens the current generated in the coils of wire by the magnetism of the iron core. It need scarcely be added that the action of the north pole on the neighbouring turns is quite analogous, and, from the preceding considerations, we can clearly see that the two total currents of opposite direction, generated by the magnetism of the iron ring unite with the currents produced by the direct

Fig. 11.

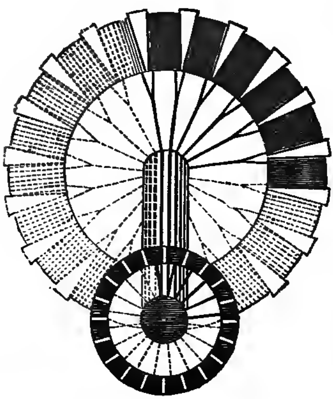


influence of the magnet poles on the coils, and which also flow in contrary directions.

The two intensified currents which are thus generated in the wire system surrounding the ring can be collected at the neutral points, Fig. 8, *p p'*, where their directions meet; and as shown in Fig. 11, *a*, they can be united into a single current and be conducted away, like as the current from the cells of a galvanic battery, connected for quantity, Fig. 11, *b*. Pacinotti has effected this collection by dividing the wire coiling surrounding the ring-armature into groups, and by giving to the separate parts of his machine the form shown in Figs. 12 and 13.

The iron ring, which moves between two magnetic poles, has sixteen grooved spaces in it, and these serve to receive sixteen wire coils, Fig. 12, all wound in the same direction. The end of each coil is soldered on to the commencement of the next, so that the turns of all the coils unite to form one continuous helix. Wooden wedges are driven into the recesses of the iron ring, and separate the coils from each other. From the joints at which the terminal wire of one coil and the wire commencing the next are soldered together, copper wires branch off and run from the inner side of the ring to the shaft. There these lead to several brass terminal pieces, insulated from each other, and forming a ring, fixed to the shaft of the machine; Fig 13. Two contact rollers, *k k*, bear on this ring, and are placed in such a position that they are always in contact with those brass pieces that are attached to branch wires leading from the solderings, *p p′*, Fig. 8, momentarily at the neutral points.

Fig. 12.

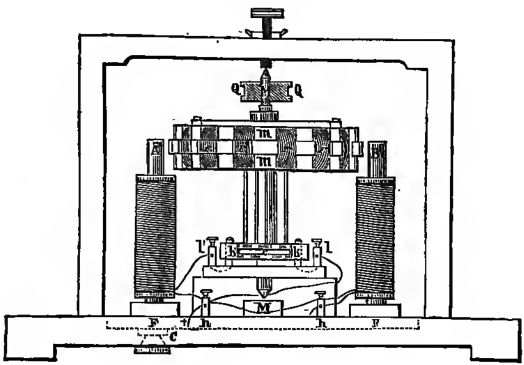


If the conducting wires are connected with these contact rollers, sixteen total currents will traverse the circuit at every revolution of the ring; for every one of the sixteen solderings passes each of the neutral points once. All these currents will flow in the same direction without a commutator being necessary; here, then, is a basis for the construction of electric machines for continuous currents.

The construction of the ring-armature was afterwards considerably improved by the Belgian inventor, Gramme, and the ring-armature employed by him will be more fully described in the chapter on machines generating continuous currents.

A further advance in improvement of electric machines was made by H. Wilde, of Manchester, in 1866. Wilde conducted the currents generated in a Siemens' cylinder-

Fig. 13.



armature, *c c*, Fig. 14, by the permanent magnets *M M*, through the coils of a large electro-magnet, *E E*, after they had been rectified by a commutator. This electro-magnet induced currents in a second Siemens cylinder-armature, *K K*, and these, of course, were of considerable intensity, because the armature was moving in a very powerful magnetic field. With a machine constructed in this way results were obtained such as had not been approached previously by any electric machine. Wilde later on constructed a machine with which he obtained still stronger currents. This he did by leading the currents

induced in the armature $K\ K$ through the coils of a second electro-magnet of very great dimensions, and by making this magnet act on a third cylinder-armature, in the wire of which was generated the current to be used for doing work.

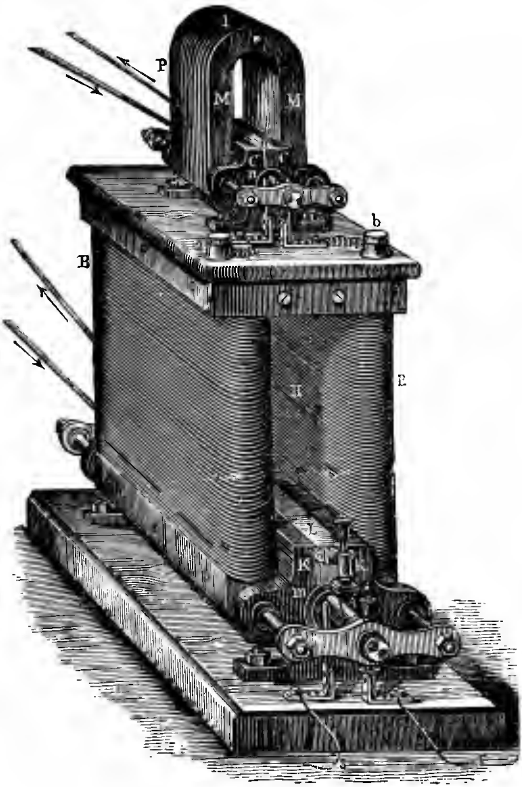
Wilde's machines soon found wide application in practice, and a number of them were employed in the celebrated galvano-plastic works of Elkington, in Birmingham, for obtaining galvano-plastic deposits on a large scale; some were used for the production of the electric light in photographic studios, and others again were employed in Whitechapel for preparing ozone as a bleaching agent.

Nevertheless, even these machines left much to be desired. It appears that through the heating of the iron cores, the current was considerably weakened after a working time of several hours, and it could not be kept constant long enough to be employed with advantage in the production of the electric light for lighthouses. The causes of the heating of the iron cores are discussed in another part of this book.

In all the machines yet described, the electric currents were induced by means of steel magnets, or, as in Wilde's machine, by magnets that were magnetised by the current produced in another machine. Such machines are usually called "magneto-electric" machines, to distinguish them from the "dynamo-electric" machines. In the latter the inducing magnets, "field" magnets, as these are termed, have cores of soft iron, which, at starting, only possess a very small trace of magnetism; this trace is however, sufficient to induce a weak current in the coils of the rotating armature, which current is then used to strengthen the magnetism of the field or inducing

magnets. This is done by the current being conducted through the wire coils surrounding the soft iron cores, which are accordingly magnetised more strongly, and now

Fig. 14.



induce a new but stronger current in the coils of the armature. The new current again increases the magnetism of the iron cores, by being conducted, like the previous one, through their wire coils. By this reciprocal

action, currents are generated in the armature-coils far surpassing in strength any that can be produced with machines of the same size, having only steel field-magnets. The machines without permanent magnets have been named dynamo-electric machines, or, shortly, dynamos.

Siemens, in Berlin, and Wheatstone, in London, almost simultaneously discovered the principle of the dynamo-electric machines. Siemens perhaps, deserves the right of priority, as in December, 1866, he had made experiments, before several Berlin scientists, with a machine in which there were no permanent magnets.* In the middle of January, 1867, he communicated his discovery to the Berlin Academy of Science: whilst it was only in February that Wheatstone communicated the result of his discovery to the Royal Society in London, in a paper entitled: "On the Augmentation of the Power of a Magnet by the Rotation thereon of Currents induced by the Magnet itself." These results agreed fully with those obtained by Siemens. Curiously enough, the discovery of the Berlin physicist was made known by his brother Dr. William Siemens, at the same meeting of the Royal Society as that at which Wheatstone delivered his lecture; and Wheatstone's communication immediately followed that of Siemens.

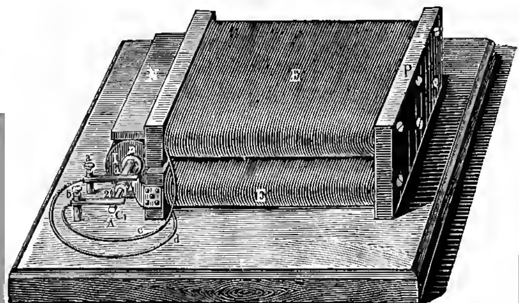
The simplest kind of dynamo is shown in Fig 15.

E E are two plates of soft iron, each about 60 cm. long 50 cm. wide, and 10 cm. thick. They are united at one end by a third plate, *P*. Each of the plates *E E* is sur-

* The German scientific writers, have in their good fellowship for their countryman, generally overlooked the fact that Wheatstone must also have experimented; and there are several scientific men who claim to have seen his machine at work at the earlier time indicated as that occupied by Siemens with exhibition in Berlin. The honour, however, can well be divided.

rounded by coils of well-insulated and rather thick copper wire, about 27 m. long. The coils on each plate are wound in such a way that they may be considered as constituting a single coil, whose terminals, *c*, *d*, lead to the binding screws *b* and *a*. *I* is a Siemens' cylinder-armature, which rotates between the projecting ends of the iron plates. One terminal of its coil is connected with the shaft *A*, and the other terminal is connected with a copper ring, fixed to the shaft, but insulated from it. A spring, 2, in connection

Fig. 15.



with the screw *b*, bears on the shaft *A*, whilst a spring, 1, connected with the screw *a*, bears on the copper ring *R*. Before using the machine for the first time, the soft iron plates *E E* are slightly magnetised, by connecting the wires *c* and *d* with a galvanic cell, and causing a current to traverse the coils surrounding the iron cores; when this ceases a small quantity of residual magnetism is left. However, it is not necessary to do even this, for through the influence of terrestrial magnetism, a slight magnetic polarity is induced in all soft iron plates that lie in a certain position, and this magnetism is quite sufficient to induce the first current in the armature of a dynamo-

electric machine. After such a machine has once been made to give a current, there is always enough magnetism remaining, at any time, to generate electric currents.

If the cylinder-armature is set in motion, alternating currents will be generated in its coils, during its revolution between the poles. These currents are rectified by means of a commutator, omitted in the figure; and as the terminals of the armature-bobbin are in connection with the terminal wires of the coils surrounding the iron cores, through the screws *a* and *b*, the currents encircle the iron cores, which will finally, after a certain speed of revolution of the armature has been attained, be magnetised to the maximum extent possible; in other words, the machine reaches the maximum of its efficiency, and the powerful currents generated in the armature manifest themselves by a great spark if the circuit is broken at any point. This spark can, for instance, be used to explode mines or torpedos, and so forth. Or the powerful currents of the machine can be used as in Siemens' "alarm-bell inductor," to ring large signal-bells in stations, and to work other signalling apparatus.

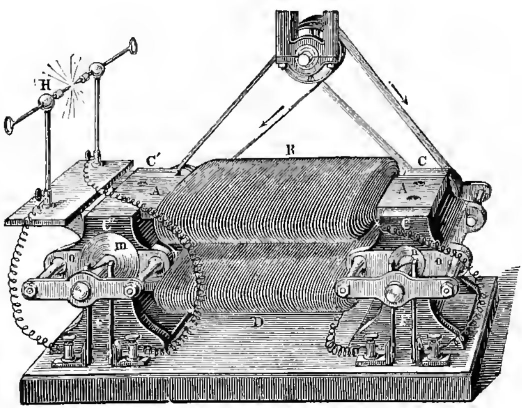
An important modification of the dynamo-electric machine was carried out by an Englishman, Ladd, only four weeks after the date of the papers previously mentioned. He sent a description of his dynamo, to the Royal Society on the 14th of March, 1867, and exhibited it at the Paris Exhibition in the middle of May, 1867.

The specialty of this machine was that the two iron plates were not connected with each other, but were converted into two electro-magnets, between whose poles rotated two armatures, Fig. 16, one of which served to strengthen the magnetism of the iron plates, according to the dynamo-electric principle, whilst the currents from

the other could be used in doing work, that is, in producing the electric light, or obtaining galvano-plastic deposits.

Later, the firm of Siemens and Halske, of Berlin, also constructed machines with several armatures, and obtained particularly good results with a machine consisting of three pairs of plates lying horizontally and parallel to each other. These were converted into six electro-magnets when the machinery was set in motion. Six armatures

Fig. 16.



revolved between the twelve poles, and the currents generated could be combined in the most varied ways by means of specially-constructed commutators.

Other constructors, too, gradually changed and improved the dynamo-electric machines in various ways. All these improvements, however, contained nothing new in principle, and only dealt with the arrangement of the separate parts. A change in the principle of the electric machine has not taken place since the discovery of the

dynamo-electric principle. Accordingly, all the machines described in subsequent chapters, and at present used in practice, depend on modifications and combinations of the historical apparatus we have considered.

CHAPTER I.

MACHINES GENERATING ALTERNATING CURRENTS.

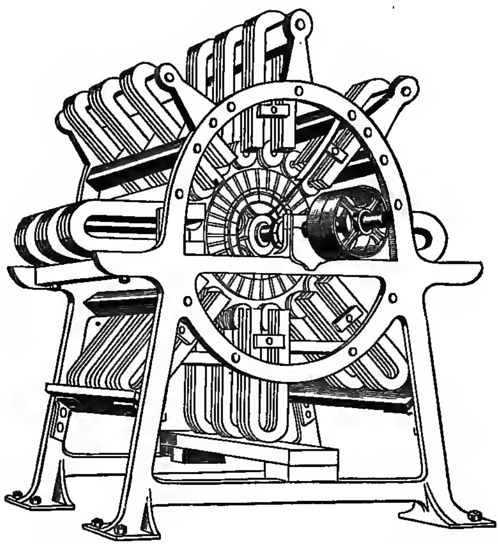
ALTHOUGH electric machines may be classified in various ways, as they may be considered from different points of view, and although they are usually divided into magneto-electric and dynamo-electric machines, yet, for a rational classification, it is preferable to group them according to the nature of the currents generated. In the two following chapters, therefore, they have been divided under "Machines generating alternating currents," and 'Machines generating continuous currents.

The first large alternating current machines were constructed by the "L'Alliance" Company, and were intended for the production of the electric light in lighthouses. They have become known as the Alliance machines. The inventor of the Alliance machines, which are still manufactured by the same Company, was Nollet, Professor of Physics at the Military College of Brussels. Nollet's machine has been much modified and improved, on the one hand by Professor Masson, who, amongst other things, omitted the commutator, formerly employed with this machine; on the other hand, by Van Malderen, engineer to the Alliance Company.

The following is the construction of the present pattern of Alliance machine (Fig. 17).

Several brass disks are fixed to the shaft of the machine, one behind the other. Each of these carries 16 armature bobbins, which are attached at equal intervals, and each disk revolves, with its bobbins, between the poles of strong compound permanent magnets. These magnets are fixed radially to the horizontal bars of the cast-iron frame, so

Fig. 17.



that two opposite poles face each other, and that the magnets arranged in a line are of alternate polarity. By means of this arrangement each bobbin is brought, when the brass disks revolve, between poles of opposite polarity, and the iron cores are converted into magnets, which induce powerful currents in the wire coils of the armature-bobbins. These coils are wound in such a manner that they may be considered to form a single large helix, one

end of which is fixed to the shaft of the machine, the other leading to a ring fixed on the shaft, but insulated from it. The alternating currents are conducted into the external circuit through springs which bear on the ring and shaft.

The Alliance machines usually carry, on the shaft, 4 or 6 of the brass disks, and accordingly the number of armature-bobbins, that move past the poles of the 40 or 56 magnets, is 64 or 96. As, in each revolution of the disks, each side of the 16 armature-bobbins passes 16 magnetic poles, it follows that the current changes 16 times in each revolution; and as in practice the shaft makes 400 revolutions per minute, when a steam-engine of about 5-horse power is used, there are about 100 changes of current per second. The intervals between the currents are, therefore, so short that they scarcely come into consideration, and, for certain purposes, the currents, taken together, may be regarded as a single current.

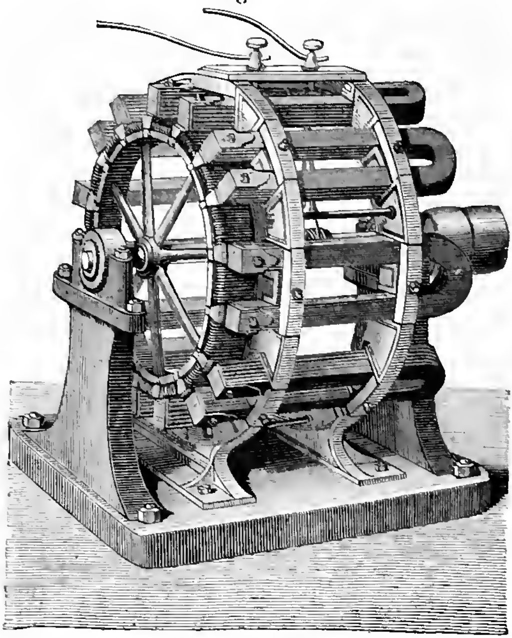
As regards the dimensions and construction of the separate parts of the Alliance machine, the following data, given by Count du Moncel, may be of interest.

The horseshoe magnets are made at the works of Alvarre; each weighs 20 kgrs., and each is composed of 5 or 6 steel laminæ about 1 cm. thick, screwed together. In order to have the poles as uniformly magnetised as possible, bars of soft iron are attached to the ends of the steel magnets. Each complete compound magnet can carry three times its own weight.

The bobbins of the Alliance machine have gradually undergone much modification. At present they consist of iron tubes, which are slit through the whole length. These are enclosed in brass cylinders, also slit along the middle, and on which the wire-coils are wound. Each

bobbin is 10 cm. long, and has a diameter of 4 cm. The length and cross-section of the wire depends on the resistance of the external circuit, also on the number of bobbins and the work that the machine is intended to do.

Fig. 18.



In the machines for the electric light, strands of wire are used, which consist of 8 wires, each about 1 mm. thick and 30 m. long. The wires are wound with cotton; and, to insure as perfect insulation as possible, they are dipped, before winding, into a solution of resin and turpentine, a very good insulating solution, which only very slightly increases the thickness of the wires.

With an Alliance machine of this construction, having a shaft carrying 4 disks, a light can be obtained, when a steam-engine of 5-horse power is employed, equal in intensity to that of 1,110 candles or 150 Carcel lamps (one Carcel lamp being equivalent to 7·4 standard candles). If a machine with 6 disks is used, a light of 1,480 candle-power can be obtained.

The results obtained with the Alliance machines are good, and the machines are used for the electric light in many lighthouses (those of Cape La Hêve, near Havre; Cape Griz-Nez, near Calais; Kronstadt, Odessa, and others); but only a small number are made, for the construction is very complicated and costly, compared with that of more recent machines.

De Meritens' Machine is considered by many engineers to be the best alternating current machine, and certainly very good results are obtained with it. This machine, especially the latest pattern, is not unlike the Alliance machine in appearance, but differs considerably in the peculiar construction of the armature.

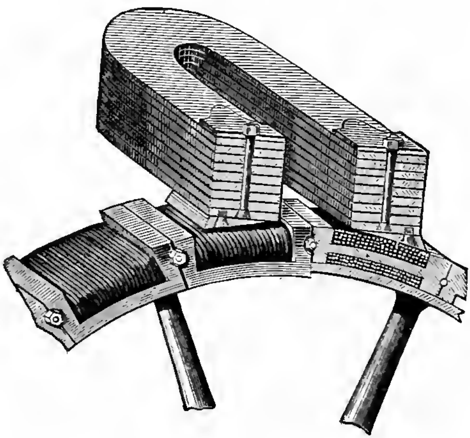
The armature consists of an eight-spoked wheel, to the rim of which 16 bobbins are fixed in such a way that the iron core of one bobbin forms the prolongation of the iron core of that preceding it. All the iron cores together form a ring, as shown in Fig. 18.

The cores consist of 50 iron plates, 1 mm. thick, and at each end they have iron pole-pieces composed of similar plates, Fig. 19. The pole-pieces of each bobbin are connected with those adjoining by bars of copper. All the coils of these bobbins are wound round the iron cores in the same direction, forming a single long helix, whose terminals lead to two copper rings on the shaft of the machine, but insulated from it and from each other.

Two copper springs bear on these rings and conduct the current into the outer circuit.

The 8 inducing, or field, magnets, which are fixed to the outer framework of the machine, Fig. 18, are compound steel magnets, and are provided with pole-pieces, Fig. 19, so that the armature-bobbins revolve as near the magnetic poles as possible. The magnets are placed in such a way

Fig. 19.



that poles of opposite polarity are always nearest to each other. When the armature is caused to revolve, the bobbins pass close under the poles of the magnets; the soft iron cores are magnetised, and alternating currents are induced in the wire coils, which are intensified by the direct action of the magnets on the coils.

This arrangement, which brings the wire coils of the armature into the direct magnetic field of the permanent magnets, is one of the chief advantages of the De Meritens machine. The construction is also particularly prac-

ticable, as the separate parts of the armature can, if necessary, be easily removed, without disturbance of the other parts, an absolute impossibility in many other machines.

Another generator, which closely resembles the Alliance machine, is that of Holmes. Indeed, it is almost identical in construction with the Alliance machine, only that Holmes, who has constructed a number of different patterns, has, in his last, replaced the steel magnets by V-shaped cores of soft iron, wound with wire coils, to form electro-magnets under the current from the machine. The cores of soft iron are attached to a disk which rotates in front of a second fixed disk, to which the armature-bobbins are bolted. The coils of these bobbins are not connected with each other, but are united in groups, so that the machine can generate several currents at the same time, each of which can be used independently, so that one machine can work several separate electric lights at the same time.

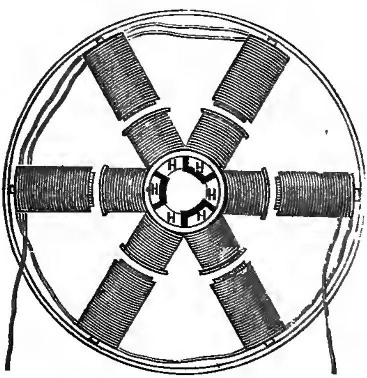
In order to rectify the currents, the machine is provided with a commutator.

Weston's machine for galvano-plastic purposes (Weston's light-machine is described in Chap. II.) consists of an iron drum, on the inner surface of which six cast-iron electro-magnets are fixed radially, each reaching to about the middle of the radius of the drum. Six smaller magnets, fixed radially to the hub and shaft of the machine, revolve close under the poles of the larger magnets, Fig. 20. These smaller electro-magnets form the armature, and the coils of two are united into one circuit, so that three horseshoe magnets are obtained, in the coils of which alternating currents are generated, and these are collected and rectified by a specially-con-

structed commutator. The wire coils of the six field-magnets form one circuit; but the wires are wound so that adjacent poles are of opposite polarity. In order to magnetise these electro-magnets, the currents generated in the armature are conducted through their coils on the dynamo-electric principle.

To prevent the coils of the electro-magnets becoming overheated, their iron cores are made hollow, and are in connection with a circulating water system.

Fig. 20.



In Weston's machine, the commutator, which rectifies the currents generated in the coils of the armature, consists of a broad cylindrical wheel, fixed on the shaft, having three teeth, and into the spaces between these teeth metal plates are inserted. These are connected with each other, but are insulated from the wheel. Three terminal wires, of the same sign, lead from the armature to the teeth, whilst the other three are connected with the little metallic plates. As each of the metallic plates is diametrically opposite to a tooth of the wheel, it is only necessary to let two springs bear on the commutator, directly opposite each other, to collect the currents. These will, at the same time, be rectified, for the metallic plates are alternately in connection with one or the other of the springs.

This construction of Weston's machine is principally

used for galvano-plastic purposes, and it is provided with a "current interrupter," the object of which is instantly to interrupt the electric circuit, so that any current generated by the polarisation of the electrodes in the galvanic bath, cannot reach the coils of the electro-magnets, when the machine is going too slow or stops. Under certain circumstances, this would reverse the polarity of the machine, and currents would be induced in the armature, whose action would redissolve the galvano-plastic deposit.

This current interrupter is described amongst the apparatus in Chap. IV.

Weston's machine was improved by H. G. Möhring, of Frankfort-on-the-Maine, and Gustav Baur, of Stuttgart.

The dynamo-electric machine of Möhring and Baur also has 6 field-magnets, and an armature consisting of 6 electro-magnets. The magnets are, however, attached to the inner surface of the cover of a cylinder, and, by means of a screw, the armature-magnets can be approached to or moved away from the field-magnets, thus making it possible to regulate the machine at any time.

Besides this, the coils of the field-magnets do not form a single helix, as in Weston's machine; but each helix surrounding a field-magnet is separate from the others. The currents induced in the turns of the armature-bobbins, are conducted to an insulated pin, after leaving the commutator, and thence they enter the six wires, leading to the coils of the field-magnets, which are magnetised as in Weston's machine, so that adjoining magnets are of different polarity. The currents pass from the six terminal wires of the magnet coils to a second pin, and thence flow into the external circuit. If required, the currents can

be conducted separately through different circuits and can then be united.

This machine is also provided with a current-interrupter, as it is intended for galvano-plastic purposes.

Lontin's alternating current machine resembles that of Weston very much in the arrangement of the separate parts, excepting that the twenty-four field-magnets are fixed to the hub of a wheel on the shaft, and revolve in front of twenty-four armature-magnets, which are attached radially to the inside of a drum-like frame, and converge towards the centre; as do the field-magnets in Weston's machine. The wire coils of the inducing electro-magnets form a connected helix, and opposite poles are placed next to each other, as in the machines previously described. The current for magnetising the magnets is produced in a separate Lontin machine for continuous currents (see Chap. II.), the star-shaped wheel of which is fixed to the principal shaft of the alternate current generator. The coils of the armature-bobbins are connected with each other in pairs, and in such a way that, together, their cores form horseshoe magnets. One of the terminal wires leads from each to a binding screw on the right-hand side of the machine; and the second leads to a binding screw on the left-hand side. Conducting wires branch off from the different binding screws on both sides of the machine, and twelve alternating currents are sent through them during each revolution. By a very simple commutating apparatus these currents can be combined for quantity or intensity, or they can be united into smaller groups.

The special advantage of this machine is that neither a commutator nor contact brushes are necessary to conduct the main currents away. Brushes, or contact pieces, usually wear rapidly, for the sparks which occur burn or

very much oxidize the metal parts, if the currents are strong. This machine also possesses the advantage that if necessary the separate parts can be easily replaced without the necessity of taking the machine to pieces.

When the working rate is 320 revolutions per minute Lontin's machine generates 12 currents, each of which is able to produce an electric light of 740-candle power.

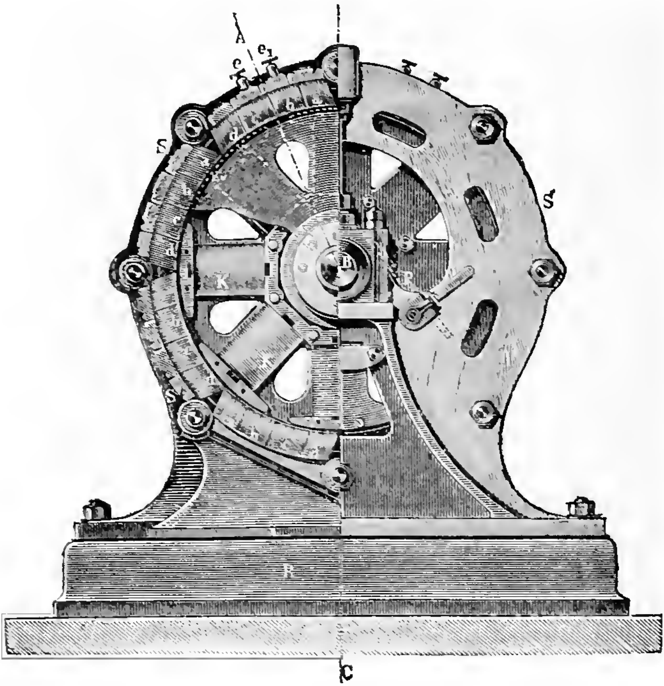
A very efficient alternating current machine has also been constructed by M. Gramme, the inventor of the well-known machines for continuous currents, with the object of producing a suitable generator for the Jablochkoff candles.

The following is the construction of **Gramme's alternating current machine.** Eight electro-magnets, *K K* (Figs. 21 and 22), provided with pole-pieces, are fixed to a steel shaft, *F*, by means of two cast-iron crowns, *H*, and an eight-sided cast-iron hub, *I*. In the older patterns of the generator, the current traversing the coils of these magnets was obtained from a small separate exciting machine, and conducted through two brushes bearing on two insulated rings. In the newest pattern this current is generated in a Gramme's ring-armature, which is attached to the principal shaft of the machine, and is brought under the influence of two electro-magnets.

The armature of Gramme's alternating current machine consists of a broad ring of soft iron, on which are wound thirty-two bobbins completely separated from each other, their turns running parallel to the axis of rotation. These bobbins are divided into eight groups, and at certain periods, during the revolution of the field-magnets, each of these groups is opposite the pole of one of the magnets, and the polarity of the magnets alternates from one

to another. Accordingly, when one of the groups of the armature is opposite a north pole, each of the adjoining groups is opposite a south pole, and vice-versâ. The position of the coils, with respect to the magnetic poles, is so

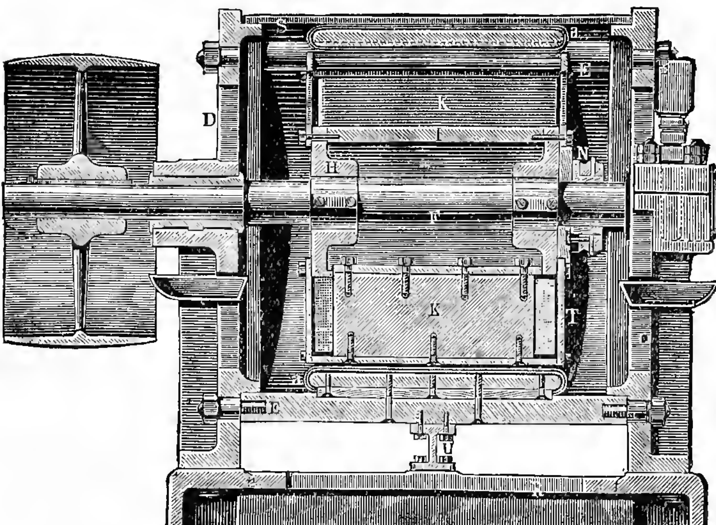
Fig. 21.



symmetrical that when the field-magnets pass before them, currents of equal intensity are induced in all the coils, *a*; similarly, the currents induced in the coils *b* are equal to each other in intensity; and currents are induced in the coils *c* and *d*, their strength corresponding to their position. If the direction of the currents, therefore, is to be

the same in all the similarly lettered coils, all that is necessary is that the bobbins, which are situated opposite different polarities, during the rotation of the field-magnets, should be coiled in opposite directions. As the terminals of each coil lead to separate binding screws, attached to the frame of the machine, it is possible to

Fig. 22.



conduct thirty-two separate alternating currents from the machine, or to combine these currents for quantity or intensity, as desired.

The framework consists of a cast-iron standard, *D*, at front and back, and both nearly circular. These are fixed to a cast-iron base, *R*, their rigidity being further ensured by eight brass bars, *E*, and an iron support, *U*. To protect the electro-magnet bobbins from injury, by action of centri-

fugal force, two thin disks, *T*, are attached to them, and these are firmly connected with the shaft. Gramme constructs three sizes of this pattern of alternating current generator.

The machine described generates current for sixteen Jablochkoff candles, and to work it 16-horse power is necessary. Its length, including the driving pulley, is 89 cm.; width, 76 cm, and height, 78 cm.; it occupies a space of ½ cub. m., and weighs 650 kg., 103 kg. of which are the copper wire. The maximum velocity of rotation is 600 revolutions per minute.

The next size is intended for six Jablochkoff candles. To work it 6-horse power is necessary; it is 70 cm. long, 40 cm. wide, and 52 cm. high, occupying a space of 0·15 cub. m. It weighs 280 kg., 40 kg. being due to the weight of the copper wire. The maximum velocity of rotation is 700 revolutions per minute.

The third size supplies four Jablochkoff candles, and requires 4-horse power. It is 55 cm. long, 40 cm. wide, and 48 cm. high, and occupies a space of 0·18 cub. m. The weight is 190 kg., of which 28 kg. are copper wire, and the maximum velocity of rotation is 800 revolutions in the minute.

As already stated, the latest pattern of Gramme's machine for alternating currents contains the generator for magnetising the field-magnets in itself. Gramme made this change because in the generator previously described transmission of the power by belt was difficult, and a disturbance was frequently caused in the uniformity of the light.

In the latest pattern, Gramme's ring-armature (see Chap. II.) is fixed to the shaft of the machine, and two of the eight field-magnets are directed radially towards this

ring, and are provided with pole-pieces, which generate two travelling poles in it (see Pacinotti's ring). The current produced in the coils of the ring is then conducted through a copper wire, which can be replaced by another of different cross-section and length, if the strength of current in the two machines is to be modified. The current, as in the older pattern, is then taken to two annular disks, both of which are insulated from the shaft and from each other; and from these, it passes into the coils of the field-magnets. Two sizes are built of this pattern.

The largest machine of this kind weighing 470 kg., generates current for twenty-four candles each of 148 to 220 candle power, or for sixteen candles each of 296 to 370 candle power. The smaller generators weigh 280 kg., and supply twelve candles each of 148 to 220 candle power, or eight candles each of 296 to 370 candle power.

Experience with the new machines shows that they are superior to the machines of the older type, especially in the production of a uniform, steady light. The firm Siemens and Halske also construct machines for alternating currents.

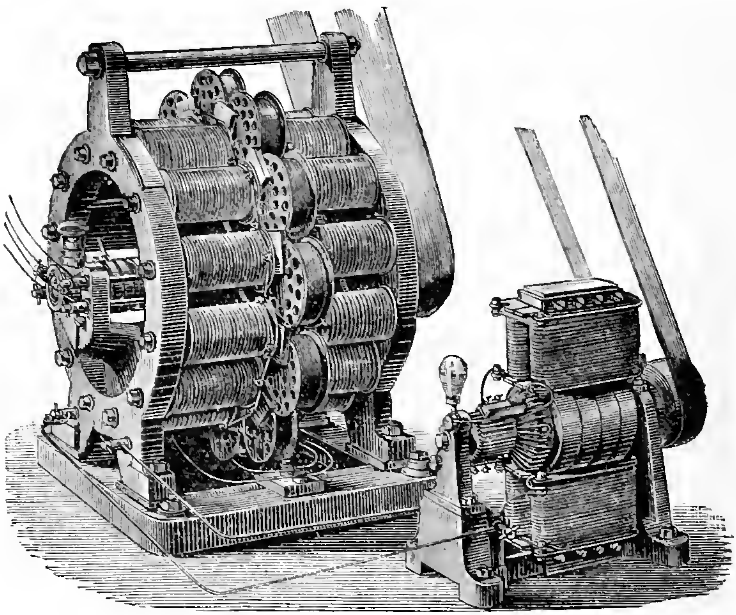
The **Siemens-Halske alternating current machines** have also been gradually modified; the fundamental principle has not, however, been changed.

The following is the construction of the latest pattern: Cast-iron standards are fixed to a base, and are held together at the top by a bar. Each of these standards carries twenty-four magnets on its inner face, and they obtain their magnetising current from a small Siemens continuous current exciting machine. This current magnetises the iron cores in such a way that adjacent magnets, as well as magnets facing each other, are of opposite polarity. The projecting ends of the iron cores of the electro-magnets are

provided with pole-pieces, consisting of flat pieces of iron, and these serve to strengthen the inducing action on the armature-coils.

In the older pattern the armature-coils are wound on an iron ring, somewhat as in the Gramme machine. In

Fig. 23.



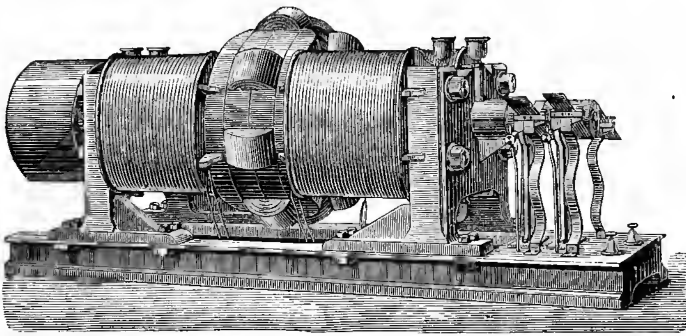
the new machine, shown in Fig. 23, they are fixed to the rim of a wheel, and do not contain any iron, but have wooden cores, which are perforated for the sake of ventilation. This so far gives the machine a considerable advantage over those previously described, as there is no change of polarity in its movable iron parts. The heating of the armature-coils, which would otherwise occur, is

obviated, and there is not the waste of work due to this heating and change of magnetism.

Another advantage arises from the arrangement of the different parts, by which the wire coils are made to rotate through fields of high magnetic intensity, formed by the powerful electro-magnets placed opposite each other.

The number of armature-bobbins, and of the magnetic fields, produced by the pairs of opposite poles of the field-magnets which face each other, is the same; the coiling of

Fig. 24.



the bobbins changes from one to another. If by a we denote all the bobbins in which the coils are wound in one direction, and b, all those which are coiled in the opposite direction, we see that at a given moment, as the armature revolves, all the alternate bobbins a will be opposite the north poles on the anterior side of the machine, and all the bobbins b opposite the south pole. Immediately afterwards the bobbins a will be opposite the south poles on the same side, and the bobbins b will be opposite the north poles. Accordingly, the current will change with each change of position of the bobbins; the number,

therefore, of alternating currents generated will be equal to the number of armature-bobbins or of magnetic fields. The alternating currents induced in the armature-coils are conducted to contact rings, which are fixed to the shaft, but are insulated from the latter and from each other. They are then conducted to the external circuit by means of contact springs or brushes, which are connected with the conducting wires leading to the external circuit.

For electric lighting, the Siemens alternating current machine renders good service, and it has proved of special use in connection with the Hefner-Alteneck differential lamps.

Brush's Machine is, perhaps, the most original, and, at any rate, the most efficient of the machines that primarily generate alternating currents (Figs. 24, 25, 26). The armature of this machine is very much like Pacinotti's ring in outward appearance; but the connection of the wire coils is different. The cast-iron core of the armature contains a vertical groove, shown in Fig. 25, which nearly completely divides it; it also has deep recesses of rectangular section on both sides, which are meant to receive the coils. The teeth thus formed are again traversed by three deep grooves. This grooving of the solid iron core serves, on the one hand, to prevent interfering induction currents being generated in the ring, which would weaken the current and heat the iron; and, on the other hand, it aids ventilation during the revolution of the armature, and serves thus to keep cool the wire coils.

The wire coils, of which there are eight, completely fill the rectangular recesses in the iron core, and every pair of diametrically opposite coils are connected with each other, whilst the terminal wires are conducted to the four com-

mutator rings, where they are attached to two segments, insulated from each other. The current generated in the two bobbins is conducted from these segments by means of brushes, consisting of slit pieces of sheet copper. Fig. 24 illustrates a machine for lighting sixteen arc-lamps.

The commutator, which consists of four copper rings, differs considerably from all those that have been described, and is undoubtedly one of the most interesting features of the Brush machine.

The construction of a commutator ring is shown in Fig. 26. Every ring consists of two segments, *S S*, which approach each other very closely at one point. They are there insulated from each other by a small air space, whilst between the other two ends there is a piece of metal, *T*, which is insulated from them, and corresponding to $\frac{1}{8}$-revolution. This is called the "insulator," and serves to exclude that pair of bobbins from the circuit whose coils are at the moment in the neutral position, during the revolution of the armature. For when the bobbins are in this position, one of the brushes presses against the "insulator," the pair of bobbins is excluded from the principal circuit, and, what is more important, no current can traverse their coils, as there is no closed circuit.

The four brushes, each of which bears on two of the commutator rings, can be shifted concentrically around the shaft of the machine, the proper regulation of the generator at any time being thus possible. They are pressed against the commutator rings by strong clamps. The conductors leading from the brushes are of thick strips of copper.

The armature, whose coils are separated by segmental cylindrical sections of the iron ring, similar to the

wooden wedges in Pacinotti's ring, rotates very near to and between the poles of a pair of powerful horizontal horseshoe magnets, the iron cores of which are a little flattened, and have similar poles facing each other. To prevent the shaft of the machine from being displaced lengthways, it has grooved bearings in the journals as in the case of the shafts of screw-steamers. The segmental ring-shaped pole-pieces exert a very powerful inducing

Fig. 25.

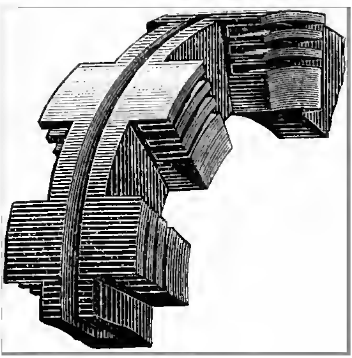
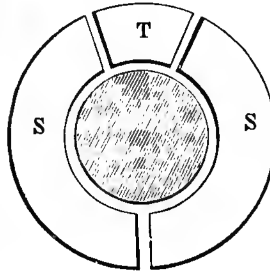


Fig. 26.



action on the whole armature, with the exception of the bobbins in the neutral position.

In a lecture given by Brush in America, he explains that the arrangement of the field-magnets is such that the current generated by each pair of coils is alternately conducted through the coils of the electro-magnet and the external circuit. Thus, during each complete revolution, every pair of bobbins once supplies the magnets with a current and once the lamps. In one position of the ring some of the armature-coils send their current through the coils of the magnets, and the others are in

connection with the external circuit. During the next eighth part of the revolution of the ring, those bobbins that were connected with the coils of the magnets send their current into the circuit, and vice versâ.

According to Brush, the armature of the sixteen-light machine offers a resistance of about 4 ohms, and with a speed of 750 rovolutions per minute, will supply 16 to 18 lamps, each of which has an arc of about 2mm, and offers a resistance of $4\frac{1}{2}$ ohms, so that the machine generates a current which is able to overcome an external resistance, including that due to the electro-magnets, of about 80 ohms, or a resistance nearly twenty times greater than that of the armature.

A larger Brush machine has been constructed for forty lights; and (according to Brush) actuated by 30-horse power, it gives a current of 10 ampères, with an electromotive force of 2,200 volts.

In "Engineering," Vol 31, 1881, p. 55, the following data are given in connection with the sixteen-light machine represented in Fig. 24.

The diameter of the ring is 20 ins.; the wire on the eight bobbins is No. 14, B. W. G. (= 2·15 mm. diameter); the weight of the wire in each coil is about 20 lb. (= 91 kgrs.); length of wire in one coil is about 900 ft. (= 275 m.); resistance of the four limbs of the electro-magnets is 6 ohms; the resistance of the machine from binding-screw to binding-screw is 10·55 ohms.

When working sixteen lamps, the machine made 770 revolutions a minute, and the working power was 15·5 horse power; the electro-motive force was 839 volts, the strength of current 10 ampères, and the resistance of one lamp 4·5 ohms.

CHAPTER II.

MACHINES GENERATING DIRECT CURRENTS.

THE fundamental basis on which the majority of direct or continuous current generators is constructed is the ring-armature of Pacinotti, which, however, only attains its full importance in connection with Gramme's ingeniously constructed collector.

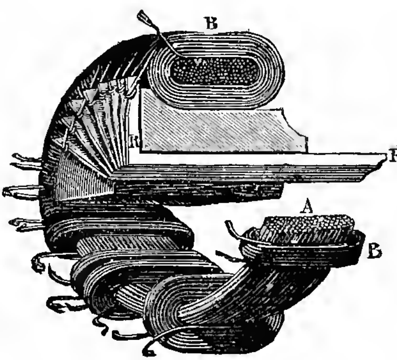
Zenobe Théophile Gramme, whose alternating current generator was described in the previous chapter, was formerly one of the employés of the "Alliance Company," and independently constructed a ring-armature in 1871, without knowledge of Pacinotti's work. In principle it agreed with the ring-armature invented by the latter.

The following is the construction of Gramme's armature and collector (perhaps incorrectly termed commutator by Pacinotti).

In order to prevent interfering, heating, false, or so called Foucault currents, the core of the ring is constructed of annealed soft iron wire, the copper conductor wound round it being composed, as in the Pacinotti ring of groups of helices. These, however, are not separated from each other by projecting iron teeth, but follow one another closely. The wire commencing each coil is con-

nected with the wire ending the previous one, and consequently all the coils together form one continuous circuit. The number of coils varies in different machines, and each consists of 300 or more turns. The points of junction all lie on the same side of the ring, as shown in Fig. 27, and are connected with strips of copper, bent at right angles, one arm of which, *R*, lies radially and edgewise along the side of the wooden hub, whilst the other arm is within this ring and runs parallel to the shaft. These copper strips, which are equal in number to the bobbins, are separated from each other by an insulating material, and their horizontal arms form a hollow cylinder (compare Fig. 29) through which the shaft passes. Two contact brushes, consisting of fine copper wires, bear on this cylinder, and are always in contact with those strips that are in connection with the points of junction in the neutral positions, p p', Fig. 8, that is the points through the connection of which the two total currents generated in the wire system flow in the same direction. Direct currents, consequently, flow through the two brushes when they are in contact with the respective collector strips.

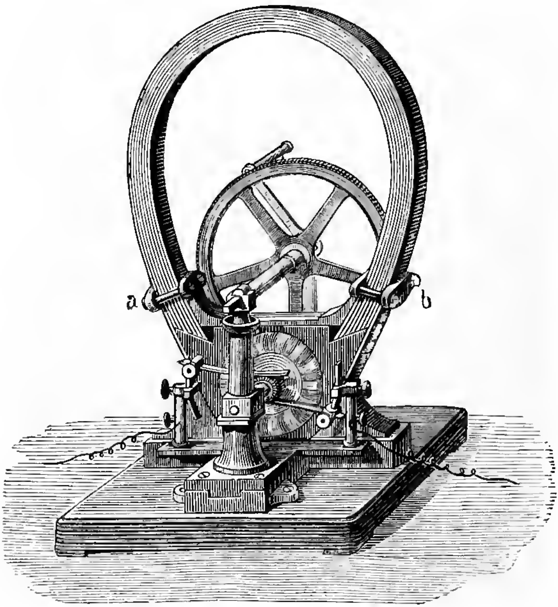
Fig. 27.



Gramme constructs his ring-armature machine in several sizes, and with various modifications. Some of

them are arranged to be worked by hand or foot power, and are intended only for laboratory use, or for small quantities of work; others are constructed to be driven by steam, and differ more or less from one another, according to the object for which they are intended. As,

Fig. 28.

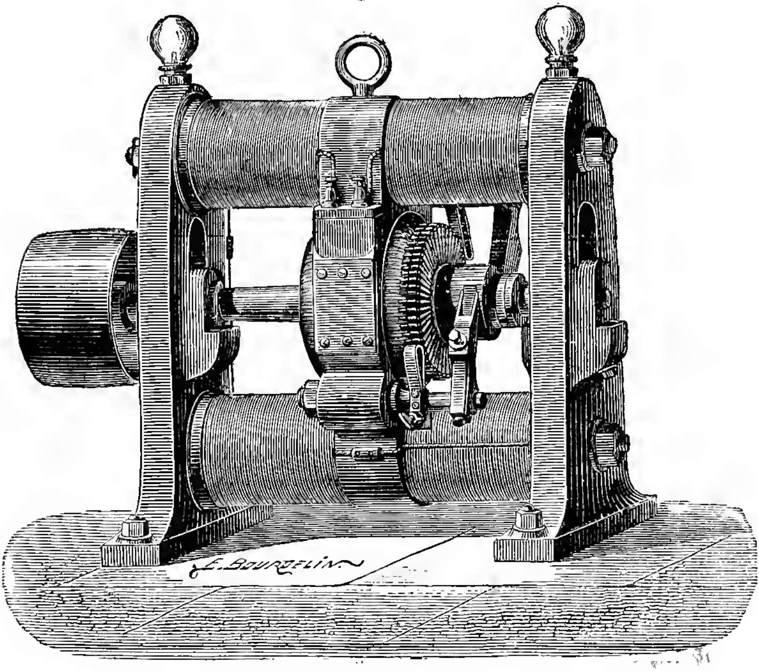


however, the principle is the same in all these generators, a brief description of some of the most useful and most frequently employed types will suffice.

Of the machines intended for use in physical laboratories, the pattern shown in Fig. 28 is the best; it is constructed by Breguet, of Paris. This is a magneto-electric machine, the field magnet of which is a so-called

laminated magnet, consisting of several steel plates, held together by clamps, *a b*, but dividing out a little at the poles. These plates are provided with massive pole-pieces, that nearly enclose the ring-armature which revolves between them. The French physicist Jamin, to whom the

Fig. 29.



construction of this kind of magnet is to be attributed, calls it a normal magnet, as in it the maximum magnetisation of the steel plates is attained. It therefore possesses far greater portative power than magnets of the same size composed of simple steel bars.

The Gramme generator with steel magnet, as con-

structed by Breguet, gives a current equal to that from three Bunsen's cells of ordinary size.

Amongst the large Gramme generators, we shall specially mention those for the electric light.

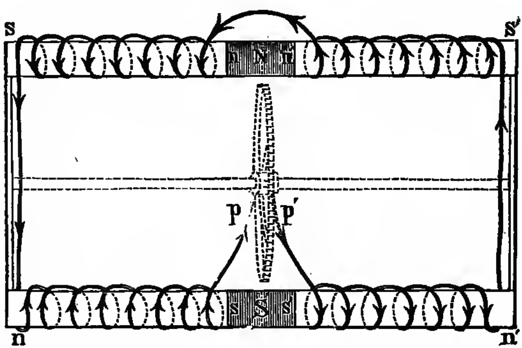
The framework of these generators consists of two iron standards, held together at top and bottom by two stout cylindrical cross-bars of soft iron. These cross-bars are converted into tripolar magnets, when the current induced in the ring-armature traverses the coils surrounding them. These coils are wound in such a way that all the poles of the tripolar magnets, opposite each other, are of different polarity. A glance at the direction of the current in Fig. 30 will make this clear.

When the current generated in the coils of the ring-armature enters the helices of the lower tripolar electro-magnet at p', and traverses them in the direction of the arrows the right-hand half of the lower magnet has a south pole induced at s', and a north pole at n'. If we follow the course of the current further, we see that there are formed in the right-hand half of the upper tripolar magnet, a south pole, s', and a north pole, n'. Again, the left-hand half of the upper magnet, n, becomes a north pole, and s a south pole; and in the left-hand half of the lower magnet, a north pole is obtained at n, and a south pole at s. Therefore, in the middle of the upper tripolar magnet, a north pole, N, is produced, consisting of the portions n n', and in the middle of the lower tripolar magnet, a south pole, S, is formed, of the two portions s s'. This is the action in the electro-magnet cores of the Gramme machine, represented in Fig. 29, and in order to utilise the double poles more completely, they are provided with heavy pole-pieces of soft iron. These nearly enclose the ring-armature, which is constructed as

described, and revolves on a steel shaft. The brushes and collector are shown in Fig. 29, on the right-hand side of the machine, and the currents, which the brushes conduct away, are not only employed to do work in the external circuit, but also to excite the field-magnets on the dynamo-electric principle, already explained.

Generators of this kind weigh 180 kgrs.; are 0·60 m. high, 0·35 m. wide, and 0·65 m. long (including the belt-

Fig. 30.



pulley, shown on the left-hand side of the figure). The copper wire used for the field-magnets weighs 28 kgrs., whilst the copper wire coils of the ring weigh 4·5 kgrs. The generator usually works at a speed of 900 revolutions per minute, and produces a current which will maintain an electric light of 10,656 candle power.

Gramme's plating-machine, constructed in 1873, also deserves mention. This generator weighs 177·5 kgrs., 47 kgrs. of which are due to the weight of the copper. It is 0·60 m. in height, and has a width and breadth of 0·55 m. With it a deposit of 600 grs. of silver per hour

is obtained in an electrolytic bath, and to do this, $\frac{2}{3}$ horse-power is necessary for driving the machine. The field-magnets are not wound with copper wires, as in the machine previously described, but both halves of each tripolar magnet are completely surrounded with a copper sheet, so that altogether the copper conductors of the field-magnets consist only of four broad copper strips or sheets.

The coils of the ring-armature, which is almost completely enclosed by the pole-pieces, as in the light-machine, consist of thick wire, flattened. The armature is thus made very strong, and is protected against the action of centrifugal force.

This arrangement of the copper windings is suitable for a generator for galvano-plastic purposes, such generators having to produce currents of low intensity, but in large quantity, and this object is to be attained only by means of coiling with thick copper wire, offering a low resistance. The field-magnets obtain their exciting current from the armature, on the dynamo-electric principle, and an automatic current interrupter is connected with the generator, as in Weston's and Möhring's generators. This prevents polarisation currents reaching the machine from the baths, and traversing it in the opposite direction.

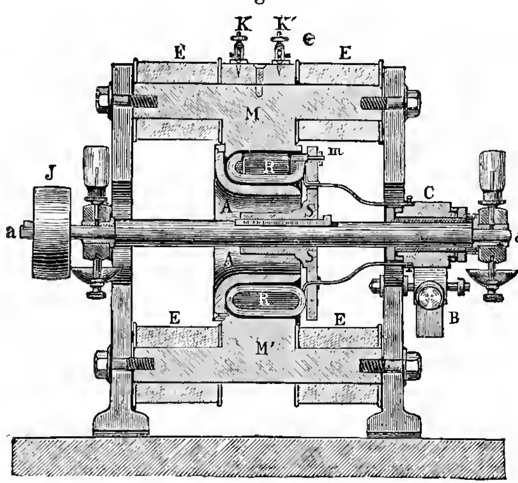
Gramme's generator for the electrical transmission of power, differs somewhat from the other machines of the same constructor, in that four pairs of electro-magnets are used, which are fixed to the inside of an octagonal frame. Of these magnets, two adjacent are at right-angles to each other, and at the point where they converge, carry a common pole-piece.

In this way four poles are generated, which are alternately of opposite polarity, and nearly completely sur-

round the ring-armature, generating four travelling poles.

One of the deficiencies which some inventors claim to exist in Gramme's machines is that only the portion of the coils situated on the outside of the ring-armature is exposed to the inducing action of the fixed magnets. This Fein, of Stuttgart, endeavours to avoid.

Fig. 31.



Fein's dynamo, Fig. 31, contains a cylindrical ring-armature, *R R*, the core consisting of a number of very thin strips of iron, insulated from each other; it is fixed to a brass star-shaped hub, *S S*, through the centre of which the shaft passes. The terminals of the coils pass through openings in the star, *S S*, provided with collars or thimbles of insulating material, and are led to the collector, *C*, which is attached to the portion of the shaft shown on the right-hand side in the figure.

The field-magnets, as in Gramme's dynamo, have iron cores, which are converted into tripolar magnets by the method of winding the coils. These are provided with pole-pieces, *M M′*, which approach the external portions of the armature coils. In addition, the peculiarly-shaped prolongations, *A A*, are screwed on to these pole-pieces. They enclose the inside and back portions of the windings of the coils, so that nearly every part of the wire is under the inducing action of the magnetic poles.

The construction of **Schuckert's flat-ring generator,** Fig. 32, is, too, such that the inducing action of the magnets on the coils is more completely utilised than in Gramme's machine. The way in which this is effected differs from that followed in Fein's machine.

Whilst in Fein's machine the ring has a cylindrical form, Schuckert has made use of a flattened ring. This flat ring is nearly completely surrounded by the pole-pieces of the field electro-magnets. The core of the iron ring consists of thin insulated plates of sheet-iron; and the collector and wire brushes are similar in construction to the corresponding parts of Gramme's machine.

Schuckert constructs various sizes and patterns of his generators, as well as machines for galvano-plastic purposes, which, with the exception of the flat ring, are almost identical in construction with Gramme's machines. He also constructs generators with two collectors, one placed at each end of the shaft.

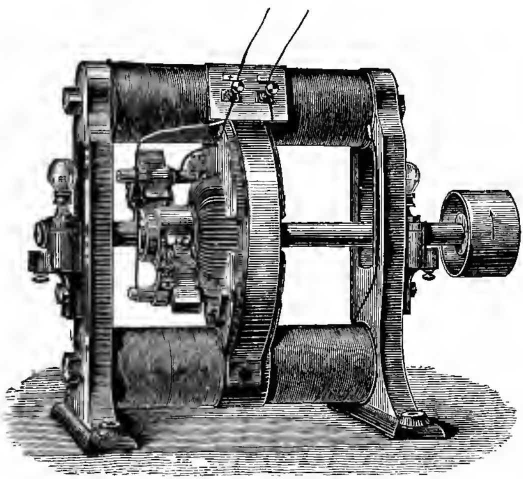
This arrangement is also employed by Gramme, and makes it possible for only a portion of the current to be used for exciting the field-magnets, and the larger part of the current solely for doing work. The advantage is that when these machines are used for galvano-plastic purposes, a polarisation current, entering the machine from

the baths, cannot produce an inversion of the polarity of the field-magnets.

For the same purpose Schuckert constructs generators with two flat rings; and these are also provided with an arrangement for combining the currents for intensity or quantity.

Heinrich's generator is another design for better

Fig. 32.



utilising the inducing action of the magnets on the armature. In this machine, the ring-armature, the core of which is composed of a bundle of thick iron wires, has a horse-shoe shaped cross-section, and the wire coils which surround it only lie close upon it on the outside, crossing over the hollow on the inside.

In order to bring those parts of the wire that lie on the outside of the iron ring as completely as possible under the inducing action of the electro-magnets, the

pole-pieces form nearly a complete ring, interrupted in two places. The cross-section of this, too, is horse-shoe shaped, and it thus very nearly surrounds the armature on the outside. The hollowing of the armature is intended to aid ventilation.

Desmond G. Fitzgerald's generator has an armature somewhat similar to Brush's ring. The coils are separated from each other by iron wedges, and the electro-magnets, which completely surround the ring, consist, for this purpose, of several pieces, which together make up a hollow ring. In this class of generators, however, when the armature is intended to rotate as close as possible to the magnetic poles, and if, at the same time, very rapid revolution is required, the builder has to overcome a great many technical difficulties. For, unless these machines are built very symmetrically, there is great danger of the armature and pole-pieces of the electro-magnets rubbing against each other, and, of course, this would soon remove the insulation, and make the machine useless.

A better solution of the problem, how to utilise the armature coils as completely as possible, is obtained in **Jürgensen's generator**. In this generator there are electro-magnetic field-magnets inside as well as outside the ring, but as the cross section of the ring and wire spirals is comparatively small, it is only important that the horizontal portions of the wire coils should be exposed to the inducing action of the magnetic poles; and the short vertical portions can be neglected; the poles of the magnets need not, therefore, take any particularly complicated shape.

To prevent Foucault's currents, the core of the armature in Jürgensen's generator is composed of separate

rings, which are insulated from each other, and consist of iron wire; and it is worth mentioning that the wire coils of the electro-magnets increase in thickness towards the poles, to obtain a greater concentration of magnetism at those places.

A generator noteworthy for its thorough practical construction is **Gülcher's dynamo**. The dimensions of the few thick copper coils surrounding the electro-magnet cores, and composed of wire strands, show that the machine is intended for currents of large quantity, but low intensity.

The flat ring-armature, which is wound much in the style of Pacinotti's ring, as may be seen from Fig. 33, rotates between four pole-pieces, which enclose it like clamps. Proceeding round the armature, the polarity of these changes from one to the other, and each unites two of the electro-magnets, whose similar poles face each other.

The four currents induced in the coils of the armature are united for quantity, and are conducted into the external circuit by means of two contact brushes.

The generator, shown in Fig. 33, will supply six Gülcher lamps of 1,300 candle power, when working at the rate of 940 revolutions per minute, and using 10-horse power. Amongst the advantages of the machine are that its magnet-coil resistance is very small, on account of the four pairs of electro-magnets being coupled parallel to each other; and that, through the arrangement of the coils, the internal resistance of the machine is only 0·265 ohm, for both the ring and the electro-magnets.

The dynamo-electric generator of the firm of **Siemens and Halske**, in which the drum-armature invented by Hefner-Alteneck is used, differs very much from the machines previously described.

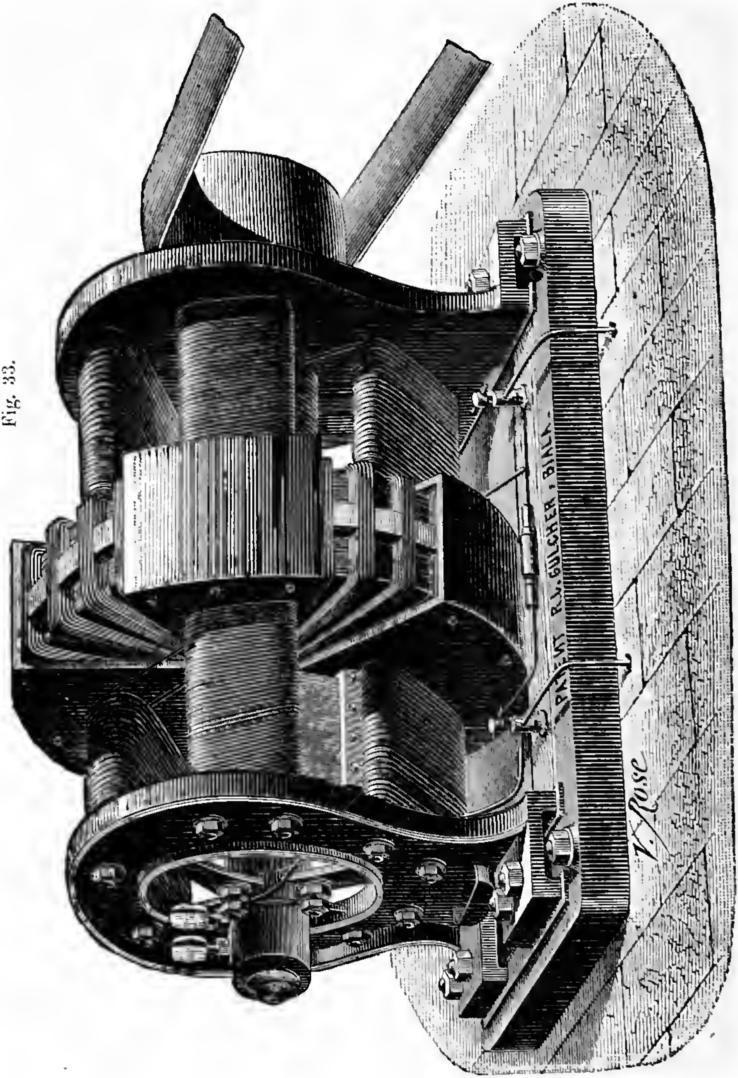
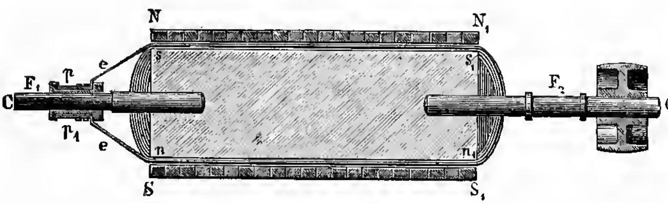


Fig. 33.

The simplest form of drum-armature is shown in Fig. 34. In this figure *N N* and *S S* are the poles of the field-magnets, whilst *s s*, *n n* include a hollow cylinder, which rotates with the shaft, and round which the wires are wound parallel with the axis of rotation. Now, as travelling poles are induced in the cylinder during its rotation, as in the case of Gramme's ring, and as the interval between the poles of the magnets and the armature is very small, the coils move in a field of high intensity.

The turns of wire wound on to the armature-drum

Fig. 34.

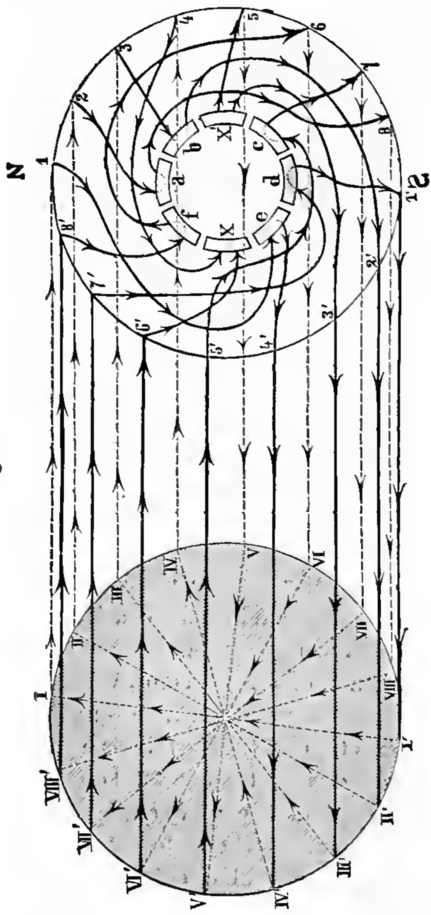


parallel to the axis of rotation are divided into from eight to twenty-eight groups, and form a continuous wire circuit. The terminal wires of the separate groups are connected with the segments of the collector, which has as many segments as there are groups of wire on the drum. The method of connection of the terminals with the parts of the collector is such that the two total currents of opposite direction, generated in the wire system, always meet in two opposite segments of the collector, and can thence be conducted into the external circuit by means of contact brushes.

The way in which the connections are made, for this purpose, is shown in Fig. 35. This figure represents a

drum-armature, on which are wound eight wire groups. The separate segments of the collector are denoted by the

Fig. 85.

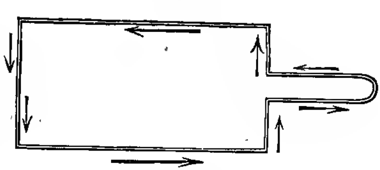


letters a, b, x', c, d, e, x, f, and the several portions of the same group are denoted by similar numbers.

If we start from the collector, and follow the course of the wire of a coil in the figure, we see that when the wire leaves the segment under consideration, it runs to the circumference on the front of the cylinder, then runs parallel to the axis along the cylinder, again crosses the back of the cylinder, and runs along the opposite side, and is finally connected with another segment of the collector.

During the rotation, one half of such a rectangularly-bent group or coil is exposed to the influence of the north pole of the inducing field-magnets, and the other half is exposed to the influence of the south pole; accordingly, currents of opposite direction are generated in both halves. For instance, in the lower half of the wire, the current will flow from left to right, whilst in the upper half, it will be directed from right to left; yet both together, form a current of the same direction, as may be seen at a glance, from Figure 36. However, as the drum rotates, that half of the coil, which at one moment was at the top, will, after a semi-revolution, form the lower half. In other words, during a complete revolution of a coil, each half turn of wire gets once into the position where the north pole dominates, and once into the position where the south pole dominates. The current will be reversed immediately after the two sides of the coils have passed the neutral points, which are equidistant from the north and south pole. The collector serves to conduct all currents of one direction simultaneously to one terminal, whilst it conducts the currents of the opposite direction to the

Fig. 36.



other terminal; that is, the currents of opposite directions are, by it, united to form currents of the same direction. This is made possible by the ingenious manner in which the inventor of this collector has arranged the connection of the wires of different coils with the separate segments of the collector. This arrangement is such that the opposite currents meet, as in Gramme's collector, in two diametrically opposite segments of the collector, and they are, as it were, coupled for quantity. If by + we denote, in Fig. 35, the ends of the wire in which the current flows from the circumference of the collector disk to the centre, and by −, the ends in which it has a direction from the centre to the circumference, we see that two + wires unite at the collector segment x, and two − wires at the collector segment x'. In Fig. 11, we have already shown how it is possible to obtain a direct current by connecting the conducting wires with the respective segments. The method of conducting the current away is, accordingly, exactly the same in the Siemens-Halske drum generator, as that employed in the Gramme generator; that is, the conducting wires are always in contact with the two metallic segments of the commutator in which the currents meet; and through the revolution of the drum, all the commutator segments come into this position in turn.

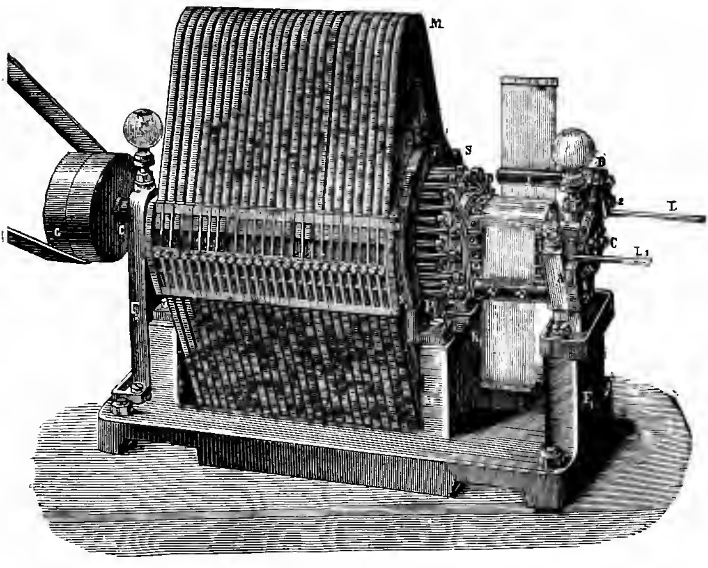
The drum-armature now described is employed in a large number of generators constructed by the firm Siemens and Halske; and as generally, these machines have a similar construction, it will be sufficient to describe only a few of them.

Fig. 37 represents a magneto-electric generator by this firm. This machine is constructed to be driven with a belt, and is very similar to the small magneto-electric

generators of the same firm, which are worked by the hand or foot.

The drum-armature of this machine rotates between the pole-pieces, which closely clasp it, of fifty V-shaped steel magnets, twenty-five of which are at the top, and

Fig. 37.



twenty-five at the bottom, placed with their similar poles opposite each other.

The poles of the top and bottom pairs are connected by soft iron pole-pieces, screwed on; and magnetic fields of fairly high intensity are thus produced, in which the drum-armature rotates. The collector and brushes are shown on the right-hand of the figure.

When the drum is caused to rotate, currents are in-

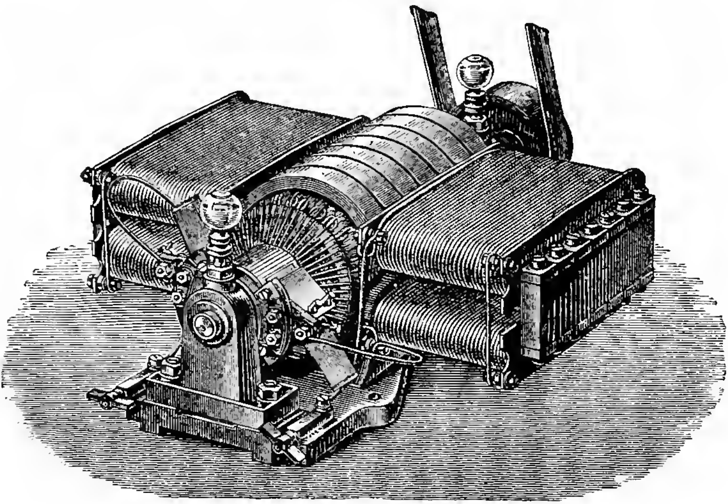
duced in the coils surrounding it, by the direct action of the field magnets. These currents are made to flow in the same direction by the collector, and are conducted to the external circuit by the contact brushes, *R R'*. From the construction of the drum-armature it will be perceived that in this type a greater proportion of the total length of armature conductor may be brought under the influence of the magnets than in the Gramme ring. In the former the whole of the wire is active with the exception of that crossing the ends of the drum whereas in the latter all the wire inside the ring is inactive. In the drum-armature we require less length of wire for the production of a given e.m.f., the advantage over the Gramme becoming more apparent as the length of armature increases, but as a set off against this, the difficulty of removing a faulty coil in machines of the Siemens type ought not to be forgotten.

In order to prevent the heating of the iron cylinder, (which occurs in machines for generating large quantities of electricity, in consequence of an undivided metallic mass moving in the magnetic field), Siemens and Halske constructed generators in which the iron core of the drum is fixed. In these generators, the armature coils are wound on a drum consisting of a sheet of german-silver, which rotates round the iron drum, at a little distance from it and from the enclosing magnetic poles. The position of the magnetic poles is the same as shown in Fig. 38, and the magnets (the horizontal portions of which are round in the older patterns) are magnetised on the dynamo-electric principle.

The rate of rotation is 450 revolutions per minute, at which is produced a light of 14,000 candles, with an expenditure of 6-horse power.

In one respect the fixing of the iron core of the cylinder is a great improvement, but experience has shown that the construction of the machines is made far more difficult, especially in the winding of the armature-coils. Accordingly, this construction is now seldom employed, and in the small generators and in those of medium size, the

Fig. 38.



coils are wound directly on to a cylinder composed of iron wires. The complicated connection, too, of the separate coils is not retained in all Siemens' generators. Thus, in the well-known Siemens machines with flat magnets, Fig. 38, a drum-armature is used, the wire coils of which are divided into a great number of groups connected similarly to Gramme's method, and lead to a collector of the Gramme pattern. In these generators, as in that shown in Fig. 37, metallic contact brushes are used, and not contact rollers,

as in the older generators. Siemens and Halske construct generators of this kind in various sizes. One size is 757 mm. long, 700 mm. wide, and 284 mm. high. The drum is wound with 28 wire coils, and the collector consists of 56 pieces. The generator weighs 200 kgrs. Its maximum velocity of rotation is 700 revolutions per minute, and 3½ horse power is necessary to work it. It will generate an arc light of 4,000 candles.

The smaller generators of this pattern are 698 mm. long, 572 mm. wide, and 233 mm. high. The armature in these generators is also wound with 28 wire coils, and accordingly the collector consists of 56 pieces. The weight of the generator is 115 kgrs. Its maximum speed of rotation is 900 revolutions per minute, and 1½ horse power is necessary to drive it. With these generators a light of 1,400 candles is obtained.

Small machines of this kind are also constructed with vertical electro-magnets, as shown in the exciting machine, Fig. 23.

A very interesting type, the **Siemens plating machine,** is represented in Fig. 39.

These generators are for the preparation of pure metals, and there are three employed in the Royal Foundries, at Oker. With each of these five to six hundredweight of copper is precipitated daily, eight to ten horse-power being required.

The electro-magnets of these machines are encircled by thick, square-sectioned copper bars, which make seven turns round each limb of the magnets. The armature also carries only one layer of windings of the bands of copper, which correspond to the coils in the other generators, and are connected with the collector by suitably bent pieces. The contact-brushes which bear on the collector

are of stout plates of copper. The several copper parts are insulated with asbestos; therefore the insulation is not

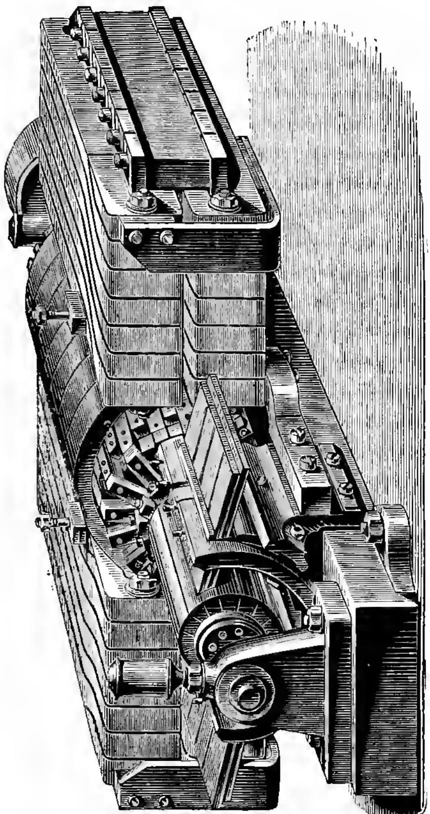


Fig. 39.

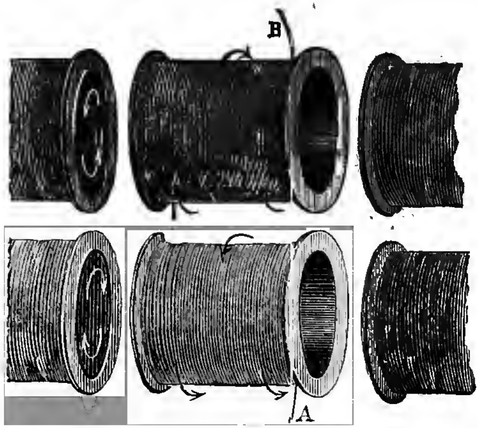
destroyed however hot the copper conductors of the machine may become.

In outward appearance the latest dynamo designed by the firm of Siemens and Halske is very like the Siemens

alternating current generator. It is constructed as follows.

Two iron standards are fixed to a sole-plate, and each of these carries an even number of electro-magnets, arranged in such a way that each is of opposite polarity both to the magnet facing it and to those right and left. The coils which surround the cores of the magnets form

Fig. 40.



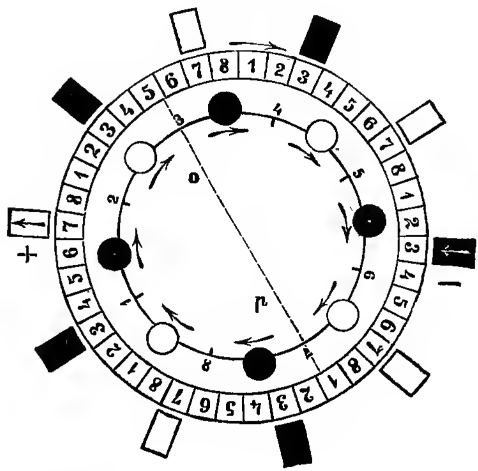
a continuous circuit, and in the magnetic fields of the poles (provided with flat pole-pieces) there revolve the armature-coils, wound on wooden cores, as in the alternating current generator. However, the number of these bobbins is two less than the number of the magnets attached to each of the standards.

The distances, therefore, between the bobbins are greater than the intervals laterally between the magnets; and during revolution the bobbins do not all simultaneously arrive directly opposite the magnetic poles. This is only the case with two of them, whilst the others are

at greater or less distance from the magnetic poles which they are about to approach. The maximum strength of current does not, therefore, occur at the same moment in all the bobbins; but occurs at successive intervals of time in successive bobbins.

The coils of the armature form a single uninterrupted circuit, but the coiling changes in direction from bobbin

Fig. 41.



to bobbin. The direction of the currents induced in the bobbins during the revolution of the armature is easily determined if we suppose the armature coils and magnets to be turned lengthwise to the observer, as in Fig. 40, when we compare the direction in which the wire of the armature-bobbins is coiled with the direction of the Ampèrian currents circulating round the iron cores of the field-magnets.

If on a certain side of a bobbin the direction in which

the wire is wound is the same as that of the Ampèrian currents of the magnetic pole that this side of the bobbin is approaching, a current will be induced in the wire opposite in direction to its mode of coiling. On the other hand, when the direction of the coiling of the bobbin, and the direction of the Ampèrian currents of the magnet, are opposite on the sides facing each other, currents will be induced circulating in the direction of the coiling.

Let us denote all the bobbins and all the magnetic fields by similar symbols, when the bobbins are so placed between magnetic poles that the direction of the coils of the bobbins corresponds with the direction of the Ampèrian currents of the poles opposite them. The position occupied by the armature-bobbins, with respect to the magnetic fields, will be seen from the diagram, Fig. 41.

In this diagram, the small black and white circles represent the bobbins, and the rectangular figures the magnetic fields. We see that all the bobbins that approach corresponding magnetic fields lie in one half of the rotating armature, whilst all bobbins which approach opposite fields are situated in the other half; and whatever the position we give to the armature, such a division will always be possible.

In that half in which bobbins and magnetic fields correspond, a current will traverse the bobbins, flowing in the direction of the coiling.

Since the coils of the separate bobbins form a single uninterrupted circuit, currents of opposite direction will meet at two points in it, as in the coils of Pacinotti's ring. All, therefore, required is to unite the two currents in one circuit. This is done in the following way.

If only eight bobbins are present, as in the case illustrated by the diagram, eight insulated metallic rings are

fixed to the shaft of the generator, one behind the other. From the points at which two bobbins are soldered together, wires branch off, and are in metallic contact with the rings. In the diagram, these points of junction are denoted by the numbers 1 to 8, placed on the circle representing the armature between the symbols for the bobbins. They are so connected with the rings that the point of juncture 1 is connected with ring 1; juncture 2 with ring 2, and so on. Besides these rings, there is also a collector cylinder, and it is composed of forty pieces. This cylinder, too, is represented in the diagram, and its position is correct as regards the angle that its separate parts make with the position of the armature-bobbins and magnetic poles at the given moment. The forty parts of the collector are divided into five groups, each of which contains the numbers 1 to 8. All parts numbered 1 are connected, by wires, with the ring 1 on the shaft, and that again is connected with the point of junction number 1, by the branch wires; all divisions numbered 2 are connected with the ring which is in connection with juncture number 2, and so on.

It has been stated that the position of the armature-bobbins relatively to the magnetic poles is such that, when the armature-system rotates, it is divided into two equal parts, in which currents of opposite direction are induced, and that where these currents meet they can be conducted away and be united. In Fig. 41 the armature is supposed to be revolving from left to right; and at the given moment, all bobbins to the right of the dotted line (passing through the points of juncture 3 and 7) are approaching like magnetic poles, and those to the left of the line are approaching unlike poles. Therefore, according to the explanation previously given, the currents must

meet at the junctures 3 and 7; and as these are in metallic connection with all parts of the collector numbered 3 and 7, the currents can be conducted away at all those places. As shown in the diagram, the collecting brushes, which are indicated by the arrows marked + and —, are situated opposite two such collector portions numbered 3 and 7; and as the position of the collector-cylinder remains constant relatively to the armature-bobbins, with which it simultaneously revolves, the brushes will always bear on such portions of the collector as are connected with those points of junction in which opposite currents meet. Accordingly, currents of the same direction will always reach the circuit.

The number of armature-bobbins and magnetic fields can be varied according to certain laws, without change to the mode of action of the generator. For instance, instead of using n bobbins (as in the case given), and $n+2$ magnetic fields, we can have $n+2$ bobbins, and n magnetic fields or keeping $n+2$ magnetic fields, we can use $2n$ bobbins; that is, we can double the number of bobbins.

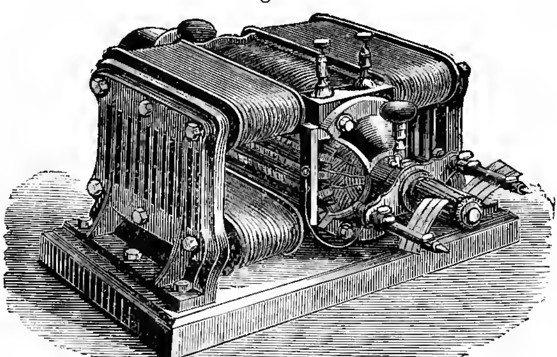
One great advantage of machines constructed on this principle is that, as in Siemens' alternating current generator, the mode of coiling is extremely simple, and the bobbins being wound on wooden cores, Foucault's currents are prevented.

Weston's dynamo-electric light machine, Fig. 42, is also worth noting on account of its advantageously constructed armature. The iron core of the armature consists of 36 thin perforated iron disks, which have 16 indentations on their circumferences, so that they look like 16 toothed wheels. These disks are fixed one behind the other on the shaft in such a way that, when looked at along the shaft, all the teeth cover each other. The disks,

however, are not directly connected with each other, but are separated by the insertion of small washers, and, consequently, after the wire coils have been wound on, a current of air can constantly circulate in the interior of the armature, and most effectively counteracts the heating of the wires. The wire coils are wound like those in Siemens' cylinder armature; and they lie in the 16 grooves formed by the indentations in the rims of the 36 disks.

In a new pattern of the generator, 12 cylindrical field-

Fig. 42.

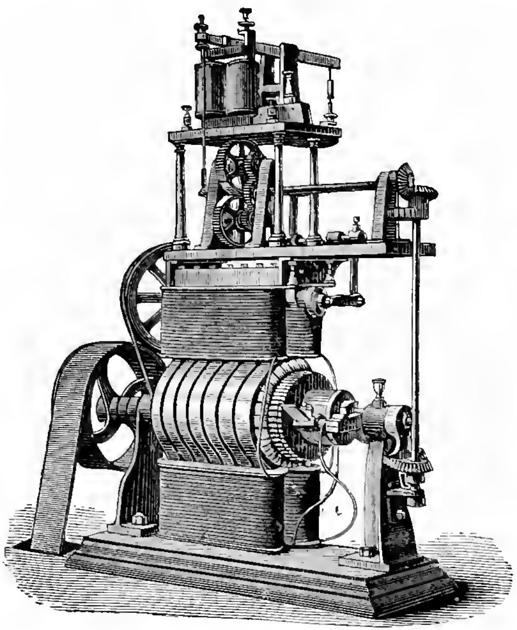


magnets are united into 6 pairs, of which the three upper ones carry a common pole-piece, whilst the three lower pairs are also united by a common pole-piece of opposite polarity. The magnet coils form an uninterrupted circuit, which receives its current on the dynamo-electric principle. The way the electro-magnets of this machine act is especially characterised by their inducing action not being the same simultaneously on all parts of a wire, but proceeding from the centre to the ends, and inversely. This is brought about by the pole-pieces, between which the cylinder-armature moves, being composed of parallel

tongues of the same length, the ends of which form an elliptical figure on each side of the armature.

The collector of Weston's generator has quite a special shape. It does not consist of separate segments running

Fig. 43.



parallel with the shaft, as in Gramme's collector, but the segment-strips, although parallel to each other, form spirals. By this means the contact brushes (which consist of from 10 to 12 elastic copper plates, divided into 3 parts by slits), are made to bear simultaneously on several segment-strips and the current is thus taken up very uniformly.

In outward appearance **Maxim's dynamo-electric generator** is like a Siemens generator, of the pattern shown in Fig. 38, whose electro-magnets are placed vertically. It is represented in Fig. 43, with its regulator, which will be described in Chapter IV. The armature of this generator consists of a cylinder-ring, round which the coils are wound as in the method employed by Gramme. Each coil, however, has four layers of wires, and the terminals of each layer are connected with two segments of the collector. For this purpose the collector consists of 64 parts.

In some of Maxim's generators there are two collectors, one at each end of the machine, and the coils are connected so that coils 1, 3, 5, etc., are in connection with one, and bobbins, 2, 4, 6, etc., with the other collector. There is also an arrangement by which the currents obtained from the two collectors can be coupled up for quantity or intensity.

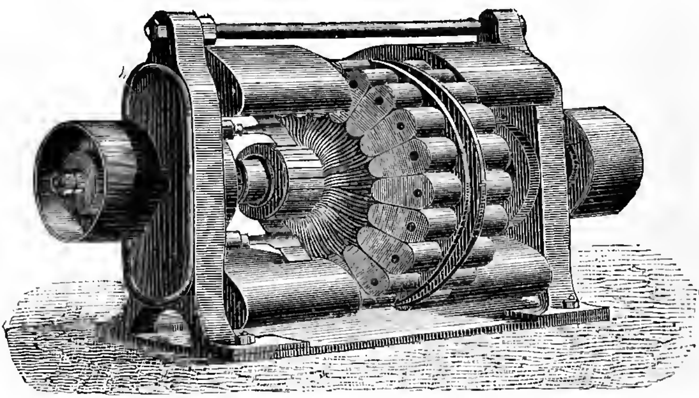
A generator favourably known in the United States is that of **Wallace Farmer** (Fig. 44). The armature of this machine consists of two disks, which are fixed to the shaft, close together; and on the outer sides these disks carry 25 flattened bobbins, with perforated cores. The coils of these form an uninterrupted circuit. Each bobbin contains four separate coils, the wires of which are connected in series. From the point where the wires of two bobbins are soldered together branch-wires lead to the segments of a collector, as in Gramme's machine.

There are four field magnets, and these are united in pairs by the iron standards of the framework, forming horseshoe magnets. Poles of opposite polarity face each other, and induce currents of the same direction in the armature bobbins. These currents, after traversing the

coils of the electro-magnets for the purpose of exciting them, pass into the circuit.

Fig. 45 represents **Lontin's dynamo - electric generator.** The armature of this generator consists of a cylinder of soft iron, which carries one or more series of conical bars of iron fixed radially, and forming the cores of the armature-coils. The field-magnets are two vertical iron columns placed one on each side of the armature.

Fig. 44.



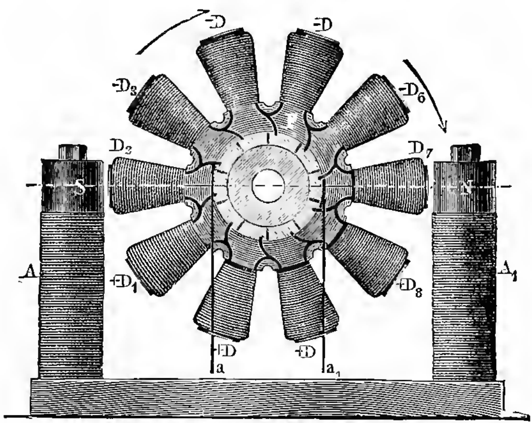
All the armature-bobbins are coiled in the same direction, and the terminal wire of each is connected with the wire commencing the next; their wires accordingly form an uninterrupted circuit. From the points at which the wires of every two coils are joined, branch wires lead to the segments of the collector; and by means of springs or brushes, the direct currents generated in the armature are conducted into the external circuit. As in Pacinotti's ring, these currents are, of course, composed of two opposite and parallel ones, and the internal process in Lontin's generator

is exactly the same, when the bobbins are coiled as described as that in the coils of the ring.

In order to convert this generator into one for alternating currents, it is necessary only to change the direction of coiling, from bobbin to bobbin.

A generator with which very excellent results are obtained in practice is **Burgin's dynamo.** The armature

Fig. 45.



of this generator consists of eight six-sided wheels, constructed of iron wire, fixed on the same shaft, one behind the other. Looked at from the front, however, their sides do not cover each other, for every wheel is displaced $7\frac{1}{2}°$ relatively to the one preceding it. The 6 sides, or chords, of each wheel-rim form the cores of armature bobbins, and accordingly, there are 48 of these. The cores of the bobbins are wound with 6 coils of copper wire, each of which contains 15m. of wire of 1·5mm. diameter. The

several coils are connected with each other in such a way that if we imagine all 48 projected on a plane, the terminal of each bobbin is connected with the wire of the bobbin following next. The wire coiling of the armature, accordingly, forms an uninterrupted circuit. From the points of junction of two coils a wire branches off to a segment of the collector; and, as in the generators previously described, the current is first conducted through the coils of the electro-magnets, on the dynamo-electric principle, and then into the external circuit. The strength of the induced current is greatly increased by the armature-coils of Burgin's machine moving close between the pole-pieces of the field-magnets. The resistance of the armature in the Burgin generator is 1·6 ohms, and that of the 4 electro-magnets, 1·2 ohms; total resistance, therefore, of the generator is 2·8 ohms. When the machine is making 1,500 revolutions the electro-motive force of the current generated is 195 volts, and it attains 206·5 volts, when the rate is 1,600 revolutions; the resistance of the external circuit being 13·16 ohms.

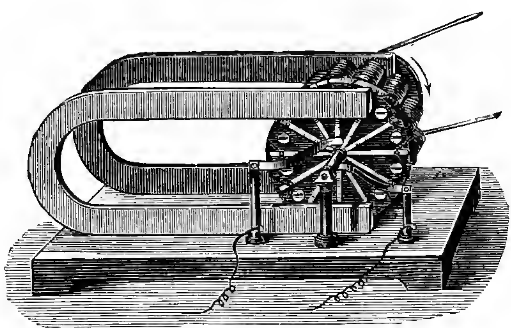
The manufacture of this machine in England has been discontinued by Messrs. R. E. Crompton & Co. the makers for some time. A description of the dynamo now made by this firm will be found in Chapter XII.

An efficient **magneto-electric machine** for continuous currents is that of **Niaudet**, Fig. 46. In outward appearance it somewhat resembles Clarke's generator. Two parallel horseshoe magnets are fixed to the base of the machine by one of their limbs, and are so placed that poles of opposite polarity face each other. A disk rotates between the 4 poles, and on one of its sides there are 12 perpendicular iron bars, arranged in a circle, and forming the cores of as many armature bobbins. The coils of these bobbins

are all wound in the same direction, and the terminal of each coil is connected with the wire commencing the next. On the outside of the disk, 12 metallic strips, on each of which the wires of two coils are joined together, converge radially towards the centre, being insulated one from another. Two springs bear on these strips and take up the currents.

Suppose the disk of the armature to be rotating in the direction of the arrow, and that the anterior horseshoe

Fig. 46.



magnet has a south pole at the top and a north pole at the bottom. Then with reference to this magnet (the magnet behind only strengthens the action) all bobbins left of a line that halves the disk and passes through the poles, are retreating from the north pole and approaching the south pole. In the lower ones a retrocession current will predominate, and in the upper ones, an approximation current; both currents will however have the same direction. On the other hand, in all the bobbins to the right of the line, retrocession currents will be induced, relatively to the south

pole, and currents of approximation, relatively to the north pole. These currents too will flow in the same direction, but this will be opposite to that of the currents circulating in the bobbins on the left half of the disk. The two opposite currents will accordingly meet at those points of junction in the armature which are exactly opposite the north and south pole, that is, at both ends of the vertical diameter of the armature disk. The springs which serve to bring these currents to a single direct current and to the outer circuit, must therefore bear on the metallic strips which are situated on this diameter as shown in Fig. 46.

Niaudet's generators have not found any very wide distribution in practice.

Edison's dynamo-electric generator is remarkable for its dimensions, and well deserves the attention of the technologist on account of its practical construction, which follows certain theoretical laws.

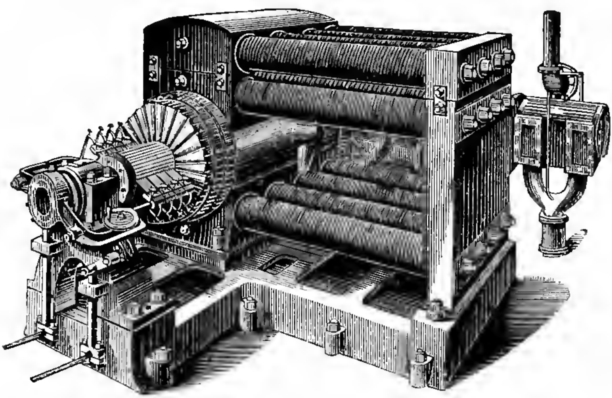
Fig. 47 represents one of the 12 large generators that are at present set up in New York, in a large central station whence a portion of the city receives the current for lighting with incandescent lamps.

The armature of Edison's generator is a Siemens cylinder armature, the construction of which has, however, undergone slight modification.

The core of the cylinder consists of iron plates, which are fixed to the shaft, one behind the other. They do not touch, but are insulated from each other with paper. Foucault currents are thus prevented. The copper coiling of the armature does not consist of insulated wires, as is generally the case, but of thick copper bars, as in Siemens' generator for depositing metals. These bars have a trapezoidal section, and are insulated from the iron cores

and from each other by air spaces. At its anterior end each bar is connected with a copper disk, which has the same diameter as the disks that compose the core; this disk again is connected with a bar, which lies diametrically opposite the first; and this bar also is connected with a copper disk situated at the back of the cylinder. This disk is connected with a third bar, and so on. Accordingly all the bars and copper disks, together represent an

Fig. 47.



uninterrupted circuit. Of course the copper disks, like the bars, are insulated from each other, and together with the disks of the core form a solid cylinder, thus considerably increasing the mechanical strength of the armature. The special advantage of the copper disks is that by their use the internal resistance of the generator is reduced to a minimum, especially at the ends of the armature on which the magnets cannot exert any inducing action.

In order to protect the bars (which run parallel to the axis of the generator) against destruction from the centri-

fugal force during the rotation of the armature, they are held together, at different points, by ties.

The cylinder armature of the generator has a diameter of 27·8 ins., and a length of 61 ins. without, and of 79 ins. with the commutator. The diameter of the commutator is $12\frac{3}{4}$ ins. The steel shaft round which the armature revolves is 10 ft. 3 ins. long, and $6\frac{1}{2}$ ins. diameter. All these dimensions show that the armature is very strongly made, and that disturbances in its working will in consequence not be likely to occur so frequently as in generators of a more complicated pattern.

Water circulates under the journals in which the shaft turns, so as to prevent their getting over-heated. Besides this, there are arrangements for automatically oiling the machine, by which the oil is carried along the shaft, whilst it is carried off before it reaches the commutator, where on account of its insulating properties, it would interfere in the electric conduction between the commutator and the brushes.

The field-magnets are 12 cylindrical cores of soft iron, excited by coils arranged on the dynamo-electric principle, and connected with each other on one side by 4 connecting pieces. Eight of these iron cores terminate in an upper pole-piece and 4 in a lower pole-piece, between which the armature rotates.

The width of the pole pieces is 49 ins., and they are $61\frac{1}{2}$ ins. high. The length of the soft iron cores is 57 ins., the diameter of the 8 upper cores is 8 ins., and that of the 4 lower ones 9 ins. The connecting pieces are 11 ins. wide and 9 ins. thick, and the total length of the field-magnet is 94 ins.

The system of field-magnets is insulated magnetically from the iron sole plate by a zinc plate 3 ins. thick.

The weight of the parts is distributed thus :—

Armature and shaft	9,800 lbs.
Shaft journals	1,340 lbs.
System of field-magnets . . .	33,000 lbs.
Zinc base	680 lbs.
Total weight	44,820 lbs.

3440 lbs. of this is the weight of the copper :—

The copper bars of the armature weigh	590 lbs.
The copper disks of the armature .	1,350 lbs.
The wire coils of the magnets . .	1,500 lbs.

CHAPTER III.

PARTICULAR APPLICABILITY OF THE VARIOUS ELECTRIC GENERATORS.

THE last two chapters will have given the reader a general idea of the construction of different electrical generators, and he may now naturally ask "What are the particular advantages of the various kinds of machines."

If we follow the division in Chapters I. and II., the question can be answered somewhat as follows.

The alternating current machines are necessary in electric lighting with Jablochkoff, Jamin and other "candles." They are always preferable to other machines when it is more desirable to burn away the carbon points in the lamps evenly, and to prevent residual magnetism in the electromagnets of these lamps, than to advantageously utilise the energy employed. Accordingly the improved patterns of these machines, for instance, de Méritens' machines are extensively employed in lighthouses.

When, however, it is principally a question of illuminating a large area, as, for instance, in the lighting of streets or large halls, then the machines for generating continuous, or direct, currents are preferable, as in this case the uneven consumption of the carbons in the lamps, is an advantage; for when the carbons have a vertical position, and the upper carbon point is the positive pole, the "crater" which is there formed plays the part of an efficient

reflector and directs a considerable part of the rays of light downwards. Numerous experiments have also proved that the machines for continuous currents are always to be preferred when it is desired to obtain the largest possible yield of work. For the conditions of resistance and rate of rotation being the same, these machines give about 35% more effect in the luminous arc than the alternating-current machines. Besides, machines for continuous currents will always have to be employed in cases where direct currents are absolutely necessary, for instance, in galvano-plastic operations, or in the preparation of pure metals. For alternating current machines, whose currents have to be rectified by a commutator, are not, as a rule, so efficient as other machines under similar circumstances. For not only is a considerable percentage of the current lost in the commutation, but, as we have before pointed out, the commutator very quickly wears, on account of the production there of sparks, whence constant disturbances occur in the working of the machine.

If we divide electric machines into magneto-electric and dynamo-electric generators and if we compare these two classes we can but arrive at the conclusion that, in principle, magneto-electric machines, and especially those in which the field magnets are electro-magnets, are the most advantageous.

We shall now try to establish the above statement.

First of all, as far as alternating-current machines are concerned, it scarcely needs proving that for working electric candles they are absolutely necessary. This follows from the construction of the electric candles themselves, and the very fact that the application of electric candles for illuminating purposes, is gradually increasing,

makes it necessary to construct alternating-current machines. For through the use of these candles the problem of the distribution of light in moderately powerful foci has been successfully solved. In fact, constructors like Gramme and Siemens whose specialty is really the construction of direct-current generators, were obliged to make alternating-current generators as well, so as not to lose the manufacture. At the present time, it is true, great improvements in the lamps of other constructors, and especially the invention of the Hefner-Altenech differential lamp, has driven the Jablochkoff candle considerably into the background, as the electric exhibition in Paris proved. Through this the alternating-current generators lose some of their importance.

The table subsequently given (taken from the "Report of the Trinity House"), shows that, economically, alternating-current machines are far inferior to those giving direct currents. From this table we see that notwithstanding its costliness and comparatively large size, the Alliance machine generated only a current capable of producing a concentrated beam of 465 to 593 candles per horse power, whereas the current of the small Siemens generator, No. 68, produced a concentrated beam of light of 2,080, and Gramme's generator, No. 2, a beam of 1,257 candles.

It cannot be denied that the recent alternating-current generators give much better results; nevertheless economically, they are still very far behind the continuous-current machines. In a number of operations too, for which electric generators are used, alternating currents cannot be employed, so that this restricts the construction of alternating-current generators.

We now return to our statement relative to the

magneto-electric and dynamo-electric generators. Experience has shown that the latter have great imperfections, for which as yet, no radical remedy has been found.

As explained in the introduction, the magnetism of the field magnets in dynamos depends on the strength of the currents generated in the armature coils; and, as this again depends on the greater or less rate of rotation of the armature, it follows that the intensity of the magnetic field fluctuates with every change in the rate of rotation; of course, again causing a corresponding reaction on the currents produced in the armature. The result is, that the strength of the current cannot remain constant, as long as a constant rate of rotation of the armature is not maintained, and this is scarcely possible even with the best steam engine or other motor. For these motors never work with perfect uniformity, and there are difficulties in the uniform transmission of the motion by belting, &c. Each irregularity, however, in the working (caused by the slipping of the strap or some similar occurrence) is accompanied by a corresponding irregularity in the strength of the current of the dynamo. Variations of current strength from the cause of inequality in the rate of rotation can, however, be easily maintained below 5°/₀.

Another still more fatal source of disturbance in the strength of current of a dynamo, are the changes which occur in the external circuit. If, for instance, the current is used for generating the electric light between two carbon rods, each change in the arc, not only causes a corresponding but a proportionally increased variation in the strength of the current of the generator.

Before the lamps are lighted the carbon points are in contact with each other, and a comparatively weak current only should be necessary for starting the light at their

point of contact. In a well-constructed regulator-lamp, the small electro-magnets ought then immediately to separate the carbon points, thus instantly employing the strong currents produced in the mean time in the dynamo-electric generator. If, however, the carbons do not instantly separate, the intensity of the magnetic field in the generator rises with each revolution of the armature, and rapidly increases to such an extent that the armature can be moved through the magnetic field only with great difficulty, and often the machine is brought to a stop. But even if the carbon points are instantly separated, the strength of current is constantly subjected to disturbing influences. For the automatic regulation of the lamp by the regulator produces a continuous reaction on the machines, causing fluctuations in the strength of current, and thus again fluctuations in the length of the arc.

The most disagreeable part, however, in this interdependence of strength of current on the varying resistance in the circuit, is that the current is weakened just when strength is most wanted, whilst it is increased, when there is no necessity for a strong current. Thus for instance when combustion increases the distance between the carbon points the arc gets longer, and when, therefore, a stronger current is wanted to overcome the greater resistance, this increased resistance weakens the current; again when the carbon points are very near together, and a weaker current would suffice, the strength of current in the generator is increased.

A good regulator lamp, it is true, modifies these occurrences; but as yet no lamp has been constructed so perfect as quite to prevent a disturbance in the strength of current.

Other changes in the resistance of the circuit, whatever

their nature, react in a similar way on the strength of current generated. If, for instance, oil or dirt gets between the brushes and the commutator, or if the binding screws get dirtied, the resistance of the circuit is increased, and the current of the generator weakened. Although these occurrences can be reduced to a minimum by careful snpervision, and by great cleanliness in the handling, as well as by employing uniformly working motors, and a method of uniform transmission of work, there still remains this defect in dynamo-electric generators, that the intensity of their magnetic fields, and consequently the current, varies with the resistance in the curcuit. In our next chapter we shall see by what preventive arrangements these fluctuations can be modified; they are not present in magneto-electric machines with steel magnets.

The magnetic fields of these machines are of constant intensity, and do not depend on the rate of rotation of the armature. Also magneto-electric generators, with electro-magnets, which are excited by currents from a separate generator, are not influenced by the disturbances in the circuit—a circumstance which gives this arrangement great advantage over the ordinary dynamo-electric machines.

If the question be asked, what are the special advantages of the various generators described in Chapters I. and II., the answer is not so easy. For although general conclusions can be arrived at as to the efficiency of the various machines from a consideration of their construction, trustworthy data are wanting. There are, it is true, numerous reports, which seem to give the reader a good idea of the advantages and drawbacks of the several machines, but, as a rule, the data given are vitiated by

private or national interests. For the data are either taken from reports of constructors, or from reports of national committees, and naturally in these an absence of party feeling is scarcely to be expected. Besides, the basis of comparison of the several machines varies in almost all published reports, and tables of comparison, which would be of real value to electro-technical science, could only be constructed by an international committee, provided with all the necessary facilities. It is much to be regretted that nothing was done in this respect during the Paris Exhibition, although a comparative investigation of the several machines would have been easy at that time; but however great, in other respects, the utility of this exhibition was, absolutely nothing was done for the advancement of electro-technical science, to throw light on the mysterious darkness which prevents a clear comprehension of the efficiency of the various magneto and dynamo-electric generators.

As, however, some of the data given by national committees, and by constructors and physicists known for their veracity, are a useful aid to the technologist, those most important have been reprinted and explained in a subsequent chapter.

CHAPTER IV.

AUTOMATIC SWITCHES AND CURRENT REGULATION.

To prevent the extremely troublesome disturbances mentioned in the last chapter, as occurring in the working of dynamo-electric generators, in consequence of changes in the external circuit, various devices have been designed.

To these belong the so-called "switches," by which an artificial resistance is inserted in the circuit, actuated either by an overseer or automatically, and generally when for some cause the external circuit is interrupted.

Siemens, Sawyer and other constructors employ these switches. That of Siemens depends on the action of a small extra magnet, through the coils of which the current is conducted when the machine is working regularly, and which, during this time, holds a small keeper connected with an extra circuit. As soon as the current in the external circuit is interrupted, a spring pulls away the keeper from the magnet; this action introduces into the circuit of the machine the extra circuit, which has the same resistance as the external circuit.

Many of the switches in use are constructed on a similar principle.

Another method of regulating strength of currents to follow the requirements of the circuit, is exemplified by

Hiram Maxim's current regulator, which excited great interest at the electric exhibition in Paris. It is represented in connection with the generator in Fig. 43.

As already mentioned, the electro-magnets of Maxim's generator are excited by a current from a small machine. In order to supply the electro-magnets with a weak or strong current as required, so as to regulate the current of the generator itself, the collector-brushes of the exciting-machine are fixed to a rocking frame, by means of which they can be shifted round the collector-cylinder. As the strength of the current taken up by the brushes depends on their being more or less advantageously situated with respect to the sectors of the collector, this current influences the strength of current of the generator. In order to alter the position of the brushes according to the requirements of the generator, the current of the latter is conducted to an electro-magnet connected with the regulator of the exciting-machine, and according to Schellen, the following action takes place (vide Schellen's "Die Magnet-elektrische und Dynamo-elektr. Maschinen," p. 509); "The electro-magnet lifts a pawl by means of a keeper attached to the end of a lever, which moves up and down between two set-screws. The pawl is caused to catch in the lower or upper of two ratchet-wheels, and is moved backwards and forwards by an oscillating bar, moved by a small crank which has a comparatively slow rotatory motion imparted to it from the shaft of the generator. If the pawl catches in one of the ratchet-wheels, the motion of the latter, as it turns, is transferred to a horizontal pin, and thence to the carrier of the brushes of the exciting-machine, by bevel pinions. The rocking-frame is turned in one or the other direction when the light-producing current is too weak or too

strong. The keeper of the electro-magnet of the regulator is pulled down more or less, and in consequence, the upper or lower ratchet-wheel is turned. This, first of all, strengthens or weakens the exciting current, and next, the current for generating the electric light."

A very effective method for preventing a sudden rise in the strength of current from a dynamo consequent upon the resistance in the external circuit being lowered, is that of exciting the electro-magnets by a shunt current, which was first recommended by Wheatstone, in England, and afterwards applied by Siemens and others with the most satisfactory results.

In this arrangement, with a lighting machine, for instance, only the lamp, the armature-coils and conducting wires are united to form the main circuit; the electro-magnets are inserted in a branch-circuit, generally taken from one brush of the collector to the other. If the resistance in the external circuit is reduced to zero, a small portion only of the current passes into the coils of the electro-magnets, and as the inducing action of the latter is thus weakened, the strength of the current is at the same time reduced.

The reader should here note that with a machine connected on this "shunt" method, the removal of resistance from the working circuit causes a *decrease* of current in this circuit; but that with a machine connected with the electro-magnets in the same circuit in which work is done, or in "series," as this arrangement is termed, the removal of resistance from the working circuit is productive of an *increase* of current in this circuit. In other words, with these two systems of connection, the same action of removing resistance from the working circuit produces opposite results.

To prevent reversal of current in the external circuit influencing the magnets, C. F. Brush surrounds the latter, in some of his generators for plating purposes, with a second coil of very fine wire which is connected with the collector-brushes, and thus forms a shunt circuit to the main or working circuit.

This system of double-winding of the electro-magnets of dynamo-machines as employed by Brush for preventing the demagnetisation of the "field"-magnets, was first used by Paget Higgs, in 1880–81, to maintain a constant electromotive force, under variations caused in the external circuit by addition or removal of lamps from the circuit. When electric lamps are ranged along the two conducting-wires leading from the dynamo, side by side, one of the two terminals of the lamp being connected to each conducting wire, the lamps are said to be put in "parallel arc" or in "multiple arc." The greater the number of lamps, the greater therefore the number of ways for the electric current to flow from the positive to the negative conductor; and the greater the number of ways, the greater will be the total flow of current. Now, with a "series" machine (in which the electro-magnets are included directly in the working circuit), the greater number of lamps causing an increased flow of current, a higher electromotive force is obtained, consequent upon heightened magnetic intensity of the field-magnets, caused by the increased current circulating in the electro-magnet coils. If this increase of magnetism were proportioned to the number of lamps added or to the flow of current, all would be easy work for the electrical engineer; unfortunately for him, the increase of magnetism does not follow any such convenient law. Besides, let us suppose that ten units of flow of current were necessary to pro-

duce a certain intensity of magnetism, to which would correspond the electromotive force necessary to properly light the lamps, then it is quite clear that five lamps would not open ways sufficient to cause enough flow of current to magnetise the magnets to that intensity necessary to produce the proper electromotive force (which for all practical purposes we may consider to be the same for one lamp as for one hundred, when the lamps are arranged in parallel arc). And if more than ten lamps are included in the circuits between the two main conductors, then it is also pretty evident that a higher intensity of magnetism would occur from the greater flow of current around the magnets, and a higher electromotive force would result, and this would cause too much current to be forced through the lamps, probably more than they were intended to withstand, ending in their destruction.

On the other hand, if the electro-magnets were included in a "shunt" circuit taken from one of the conducting mains to the other, or from one brush of the machine to the other—the electro-magnets being thus in parallel arc to the lamps—increase of the number of lamps above the normal number would cause a too great number of ways to be opened for the current to pass by the electro-magnets, subtracting current from these magnets, and therefrom the magnetism would be decreased, with the consequence that the electromotive force would also be decreased (in a much more than a proportional amount), resulting that the lamps would decrease in the amount of light given by each by this addition to their number.

We see that adding lamps, in the one case of the "series" machine would cause the destruction of those already

arranged in circuit from too high excitation, and in the other case of a "shunt" machine, reduction of current and light ensues: from these opposite effects it is not difficult to comprehend that a possible combination of these two methods of arranging the electro-magnets—"shunt" and "series"—would result in maintaining, under the case of adding, or subtracting, lamps in the circuit, a constant magnetic intensity and consequently a constant electromotive force. Such is the principle of the machines termed **compound wound**, or **self-regulating**; and in these machines a constant speed being given, with the lamps arranged in parallel arc, very great variations in the external circuit may occur, without variation in the electromotive force.

The steady maintenance of a constant electromotive force, with only one unit of current passing over the coils of the electro-magnets (ten units being supposed to maintain saturation under a "series" arrangement), clearly necessitates that the magnetic field shall initially be raised to its proper intensity. This need of an "initial field" was first proved mathematically by M. Marcel Deprez, in 1881, independently of Paget Higgs (but several months after application for patent by the latter), in a valuable contribution to the French journal *La Lumière Electrique*. M. Marcel Deprez proposed to maintain this initial field by employing two machines, one being the generator, the electro-magnets of which were wound with two equal and similar wires; the other an exciting machine. One of the wire circuits on the electro-magnets of the generator was put into connection with the exciting machine, only to maintain the "initial field;" the other wire circuit was arranged in "series" in the main circuit in which work was to be done. The system

adopted by Paget Higgs at once gave similar results, with the use of only one machine.

It is frequently astonishing to find how nearly earlier inventors were in attaining results that have finally been produced with so much thought and labour. An old machine by Hjorth, a Swede, was patented thirty years previously, in which permanent magnets were used in combination with electro-magnets in the same machine. The permanent magnets were then doubtless intended to give the necessary magnetism to start the electric current, the dynamo-electric principle being then unknown; but to-day, constructed in proper proportion, Hjorth's machine could be used to give constant electromotive force, or as a self-regulating machine. Indeed, Professors Ayrton and Perry have recently perfected a dynamo, in which permanent magnets are employed to produce an initial field with electro-magnets to provide current for the remainder of the work. An objection to such a machine will be probably found in the great size required, which is one of the most detrimental drawbacks to magneto-machines with permanent magnets.

Self-regulating compound wound dynamo-machines have been usually constructed with the main circuit, or "series" electro-magnet coils wound on the same arm or limb of the electro-magnet, as contains the "shunt" coils; some makers, like R. E. Crompton, putting the main coils, of thick wire, on first, the "shunt" coils, of finer wire, being wound above or over these other coils; Siemens, on the contrary, puts the main coils outside and the shunt coils nearest the core of the electro-magnet. Paget Higgs, however, prefers to assign one limb of the electro-magnet to the shunt coils, and the other limb to the series or main coils; very many more points that occur

in practice are covered by this arrangement, and it has been shown to be possible by a suitable combination to obtain a machine so regulated as to produce a normal current only, any deviation of a marked character from this normal current causing a cessation, or great diminution of current. The first published mathematical consideration of double-wound machines is due to Mr. R. H. Bosanquet, of St. John's College, Cambridge, and to this reference will be made in a subsequent chapter.

M. Marcel Deprez, to whom electricians are indebted for the first logical enunciations of the laws relating to current electromotive force in dynamo machines, has also shown that with a properly-arranged initial field, and with the remaining coils of the electro-magnets in a circuit shunted from the main or working circuit, it is possible to maintain a *constant current* (the former arrangement referred to maintaining a *constant electromotive force*), flowing through a "series" of lamps—that is through a succession of lamps on a single circuit—when the number of lamps is varied, provided the speed of rotation of the armature of the machine is maintained constant. But this has only been successfully accomplished with two machines, one being used as an exciting machine, and the other, the chief generator, wound as to its electro-magnets with two equal and similar wire circuits. One of these circuits is connected to the exciting machine, the other is arranged as a shunt from main to main of the working circuit.

In all these double-wound machines, certain relations have to be maintained between the resistances of electrical circuits of the machine itself, and between the amount of current and number of turns of wire led around the electro-magnets, but to this it is not now necessary to refer.

So far, however, these methods of regulation have not furnished us with an absolutely reliable remedy, especially as to any variation in the speed of the motor or irregularity of its motion. However, a comparatively short time ago, great advance was made in electro-technology, which renders it possible, to completely sever the connection of the electric generator with the circuit in which electricity is converted into work. This advance is the employment of the improved secondary batteries as reservoirs of electrical energy.

In this respect the recent improvements have made the subject of storage batteries sufficiently important to receive separate consideration.

CHAPTER V.

ELECTRICAL STORAGE.

WHEN two platinum electrodes are immersed in hydric sulphate, and are connected with a galvanometer, after a current has been sent through the whole voltametric arrangement, a current is found to flow from one electrode to the other, in a direction opposite to that of the original current. This current is called a polarisation current, and was first observed by Gantkerot in 1802. It is produced by the evolution of hydrogen at one pole, oxygen at the other; these gases change the *potential* of the electrodes, by partly adhering to the metallic surfaces, and partly by penetrating into the metal; and as soon as metallic contact in the external circuit between the electrodes is established, a current flows tending to reproduce electrical equilibrium.

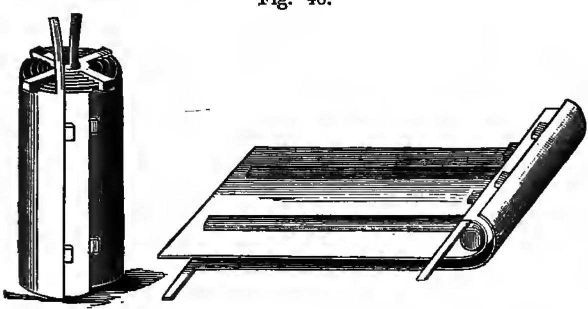
This polarisation current may be very powerful; and as early as 1803, the German physicist Ritter, of Jena, constructed a kind of voltaic battery in which only one metal was employed, the disk-electrodes of which were rendered active by polarisation. This secondary battery, by Ritter, can be regarded as the first electric storage battery or accumulator.

Planté, the celebrated French physicist, however, deserves the merit of having been the first who applied the polarising of electrodes to the construction of an efficient

battery that could be used in practice. In 1859, he constructed a secondary or storage battery, the efficiency of which depended on the chemical behaviour of lead.

The following is the construction of **Planté's Element**, Fig. 48. A broad sheet of rolled lead is placed on a second sheet of the same size, so that one sheet covers the other. However, to prevent contact between the two sheets, thick strips of indiarubber are laid between them. Each strip of rubber is 1 cm. wide, 0·5 cm. thick, and of the same length as the lead sheets; when similar india-

Fig. 48.



rubber strips have been laid on the upper lead sheet, the two sheets are rolled into a spiral on a wooden cylinder. To make the arrangement stronger, the lead spiral is held together at one end by gutta-percha clamps. The construction of the element is completed by placing this roll of lead, each sheet of which is provided with a connecting strip, in a cylindrical vessel, closed with an ebonite cover. The cover is provided with openings for the connecting strips, and an opening for pouring in the liquid, which consists of water containing ten per cent. of hydric sulphate.

Now, if the poles of such an element are connected with the poles of two Bunsen's elements, so as to cause a current to circulate through the Planté cell, lead peroxide ($Pb\ O^2$) will be formed on the lead sheet by which the current enters the cell, or the anode; and, on the other hand, on the lead sheet, or the cathode, hydrogen will be generated, tending to precipitate lead in the metallic state. The cathode obtains thus a rough granular surface, and the anode a brown coating.

Now, when the Bunsen battery is removed, after the current has been allowed to work for some time (the current should only be allowed to traverse the Planté element till small bubbles of oxygen show themselves at the anode), if the poles of the Planté element are joined, a strong current results; for now the oxygen of the peroxide powerfully attracts the hydrogen of the hydric sulphate; and the peroxide is de-oxidised; whilst the oxygen liberated combines with the lead of the cathode, and oxide of lead is formed there. The current continues as long as the cathode takes up oxygen. When the discharge current ceases, the conditions for a new polarisation current can be again obtained by recharging with the Bunsen elements; and as the discharge need not take place immediately, but can be proceeded with after several days, it appears that in a Planté cell we really have a reservoir for electrical energy.

This element, however, cannot take up a large charge immediately, but its efficiency increases to a useful degree with repeated charging and discharging. The element has to be "formed," as Planté expresses it, and this "forming" is a long, troublesome process.

When first charged, only a small quantity of peroxide is formed; and accordingly, in the discharge, a current of

but short duration is obtained. The poles have now to be reversed; that is, the pole which was previously negative must now be oxidised, and the pole which was previously positive must be reduced. The reduced lead sheet now takes up oxygen, and lead peroxide is formed on it; whilst the plate which was previously oxidised is reduced by the hydrogen. According to Planté, this process of reversion must be repeated frequently. On the first day the element must be charged and discharged from six to eight times, commencing with a quarter of an hour, and gradually increasing the length of time to an hour; the element is allowed to stand charged over night. On the second day it is discharged, and then recharged in the opposite way during two hours; again discharged, recharged afresh in opposite direction, and finally is allowed to stand charged for eight days. After eight days it is again charged during some hours without being reversed, and is then allowed to stand charged for fourteen days, and so on. In this way the capacity of the element is more and more increased. With a well-formed Planté element, a thick platinum wire of 1 mm. diameter can be made to glow, and can be kept glowing during ten minutes; a platinum wire of $\frac{1}{10}$ mm. diameter can be kept glowing for an hour.

On account of the spiral arrangement of the electrodes, the Planté element has very small internal resistance. It has a high electromotive force as well, and accordingly its construction is very advantageous. The results obtained with the elements would undoubtedly have ensured their extensive application in practice, had not their "formation" offered such a great obstacle. This "forming" is the reason why this original Planté element is scarcely employed in practice, excepting for galvano-caustic pur-

poses, although it is an extremely convenient source of electricty when once formed.

In 1883, M. Gaston Planté patented a process for the rapid formation of the well-known secondary battery, and it consists in immersing the sheets of lead (similar to those devised by him in 1860) in nitric acid, diluted with from once to twice its volume of water, for about twenty-four hours before submitting them to the action of the primary current. The cells are then emptied, thoroughly washed, filled with water acidulated with about one-tenth of sulphuric acid, and submitted to the action of the current from the primary source of electricity of which they are intended to accumulate and store up the energy. By this preliminary immersion in nitric acid, a small quantity of lead is, of course, dissolved, but the thickness of the sheets suffers no sensible diminution as, by reason of their metallic porosity, the chemical action is not limited to the mere surfaces of the sheets of lead, but penetrates into the interior of the metal, creating new interstices and enlarging the natural pores already existing, and consequently facilitating the ulterior electro-chemical action produced by the primary current.

The sheets of lead intended to be employed in the construction of these secondary cells may be submitted to the action of the dilute nitric acid and washed before being rolled up or arranged in cells; but the process is equally applicable to cells already constructed.

Secondary cells thus formed, after having been submitted for a few hours to the action of the primary current, give off a discharge current lasting for a long period, whereas when they have not previously been attacked by the nitric acid, several weeks of electric action are required, as has been shown, before they will give the same results. Re-

versing the direction of the primary current, which is so useful for the operation that Gaston Planté described in 1872 under the name of "formation," is equally efficacious in the present case, without it being necessary to so frequently effect this change. About the same time that M. Planté made his remarkable discovery, Mr. Bedford Elwell and Mr. Parker, of Wolverhampton, hit on nearly the same thing. They found that by immersing lead plates in a dilute mixture of nitric and sulphuric acids very important advantages were secured.

The method of making the Elwell-Parker secondary battery may be thus described :—Strips of sheet lead 9 ins. wide and any convenient length, weighing 2·16 lb. to the square foot, are passed through a machine which first punches holes entirely through them, and then impresses them with indentations, which act as distance pieces to keep the layers of each plate apart. The holes secure a free circulation to the electrolyte. These strips are then rolled spirally into cylinders containing, in the small cells, three thicknesses of plate each, the joints being made secure by fusing with a soldering iron, and a conducting piece of much thicker lead being fused on at the same time. Each cell contains eight of these cylinders $\frac{1}{4}$ in. apart. The lead cylinders are first placed in a bath containing a dilute solution of nitric and sulphuric acids, and left there for twenty-four hours. The effect of this bath is to minutely honeycomb the lead plates, putting them into the most favourable condition for "formation" by the electric current. There is also formed upon the surface of the plates a deposit of sulphate of lead, the greater part of which is subsequently reduced to peroxide, part of it being first washed off. The plates on being taken from the bath are washed, and then placed in the

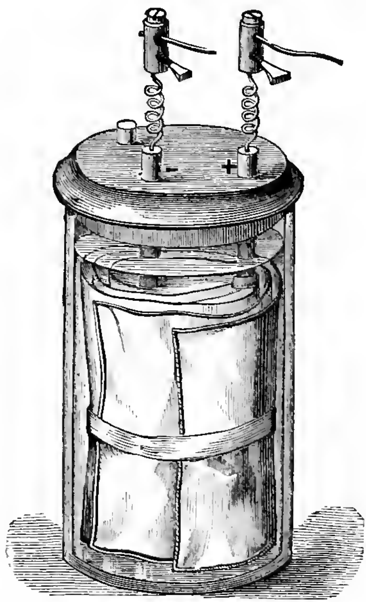
ordinary dilute sulphuric acid solution in the cell. They are then charged in one direction for six hours with a current of 12 ampères, discharged in about three hours through ten Swan 45 volt, 20 candle lamps—twenty-two cells give 45 volts—and charged again in the reverse direction. They are now ready for use. There is then no sulphate visible, the peroxide plate being of a rich, dark brown colour, smooth, hard, and crystalline in appearance, and the negative plate presenting a clean surface of ordinary lead colour.

The plates or cylinders are retained in position by notched vulcanite frames underneath, and notched distance pieces of the same material on the top, thus leaving the centre space between the plates, and a space underneath them, open for the free circulation of the electrolyte. Earthenware cells are generally used, but the company manufacturing under the patent also use wood cells, coated inside with a composition of gutta percha, which are preferable where strength and lightness are required. The quantity these cells will give out at an electromotive force of two volts, or rather more, is about 40 ampère-hours when sent from the works, that is, supposing an accumulator is required to give a current at an electromotive force of 45 volts, twenty-two of these cells will give a current of 10 ampères for four hours before any of the cells are exhausted. But the capacity of the cell may be greatly increased by occasionally reversing the charging current, as in the original Planté cell. The arrangement of the battery is very workman-like and convenient. A cell can be taken to pieces and put together again in about two minutes; and the way in which the cylinders are put together gives great stiffness and prevents deflection or bending, while the plates being free

to expand or contract, can do so without losing their shape.

It is to a Frenchman named Faure that the honour is due of having in practice and by somewhat mechanical means rendered the long "forming" of the elements unnecessary. He uses lead in a powdered condition for the

Fig. 49.



construction of his elements. These consist of two lead plates, each 200 mm. wide, one 600, the other 400 mm. long, and 1 and 0·5 mm. thick, which he coats as thickly as possible with a paste of red lead ($Pb_3 O_4$) and water. On the larger plate he puts 800 grms., on the smaller are 700 grms. of red lead. To keep the paste on the metallic plates, he places over them strips of parchment paper, and

on that a strip of felt. He then rolls up the whole system as in the Planté element, and places it in a cylindrical vessel, Fig. 49. The liquid is the same as that used in the Planté element.

When the element is thus prepared, a current is passed through it, and a thin layer of lead peroxide and lead sulphate is, according to Dr. Aron, formed on the outer surface of the red lead. This layer of sulphate then gets reduced to lead, whilst on the other plate pure lead peroxide is formed. In due course the stratum of red lead beneath gets attacked, and the action goes on till by degrees the cell is made capable of taking up a large charge.

Charging the element two or three times is sufficient to make it ready for use; the coating of red lead on one electrode has then changed completely into lead peroxide, whilst the red lead on the other electrode has been reduced to lead.

There were few trustworthy data with regard to the efficiency of the Faure batteries up to the beginning of last year; and whilst, on the one hand, Faure's improvement of the Planté battery was lauded to the skies in ridiculous advertisements, on the other hand, in consequence of this quackery, so unworthy of a scientific invention, physicists were inclined to think lightly of the Faure battery. One of the first to truly investigate the merits of the Faure batteries was Mr. Frank Geraldy, who published the results of experiments carried out by him, in partnership with Mr. Hospitalier, in the electrical journal, *La Lumière Electrique*, in which he showed that a Planté element is almost as efficient as a Faure's element of the same weight. The advantage of the Faure element over the Planté element, consists in the former being

ready for use almost immediately after its construction, whereas the latter requires the tedious "forming." We have now reliable data as to the value and efficiency of Faure's elements of the newest construction. These data are given in the journal mentioned, Vol. VI., No. 10, in which there is a full report of experiments made by a French committee, with Faure's batteries at the Conservatoire des Arts et Métiers.

The committee were Messrs. Allard, Blanc, Joubert, Potier, and Tresca, and a memoir on their experiments was also placed before the French Academy of Sciences on March 10, 1882.

The battery placed at the disposal of the committee consisted of thirty-five Faure elements of the newest construction; each element, with its liquid, weighed 43·7 kgs., the lead-electrodes were covered with red lead in the proportion of about 1 kgr. to the square metre. The liquid consisted of distilled water containing about 10 per cent. by volume of hydric sulphate. The generator placed at their disposal by Faure was a Siemens dynamo.

The resistance of the armature was 0·27 ohm, that of the field-magnets 19·45 ohms. The coils of the latter were supplied by a shunt current. By means of a regulating apparatus, employed by Faure, the exciting current was kept during the entire experiment at a strength varying between two and five ampères.

The object of the experiments was to measure:—1. The mechanical work necessary to charge the battery. 2. The quantity of electrical energy stored during the charging. 3. The electrical work actually performed during the discharge.

For this object the electro-motive force and the resis-

TABLE I. CHARGING THE BATTERY.

Date and Duration of the Experiments.	Mean Speed of Generator. Revolutions per minute.	Mechanical Work in Kgrs. mm.; measured by the Dynamometer.	Mean diff. of Potential of the Battery, in Volts.	Mean Intensity of Charging Current in Ampères.	Mean Intensity of Exciting Current in Ampères.	Quantity of Electricity taken up by the Battery in Coulombs.	Electrical Work done in the Charging. (In Kilogrammes-metres.)	Electrical Work done in Exciting. (In Kilogrammes-metres.)	Electrical Work done in the Armature. (In Kilogrammes-metres.)
4 Jan. 5 h. 30 m.	1079	2414907	82·81	10·93	2·46	216400	1814600	408400	94400
5 „ 7 h. — m.	1072	2772292	91·08	7·97	2·81	200800	1947100	676300	79100
6 „ 7 h. 30 m.	1083	3246871	92·91	7·94	2·83	214300	2028800	596100	76800
7 „ 2 h. 45 m.	1085	1135728	92·06	6·36	2·18	63000	591600	202800	19500
22 h. 45 m.		T = 9569798 t = 808750 8761048				694500	T′ = 6382100	T″ = 1883600	T‴ = 269800

TABLE II. DISCHARGE OF THE BATTERY.

Date and Duration of the Experiment.	Mean Electromotive Force of the Battery, in Volts.	Mean Strength of the Current in Ampères.	Quantity of Electricity in Coulombs.	(External) Elect. Work done in Kgrs.-mm.
4 January, 7 h. 19 m.	61·39	16·128	424800	2608000
9 „ 3 h. 20 m.	61·68	16·235	194800	1201000
10 h. 39 m.			619600	3809000

tance of the battery had to be constantly controlled, and as the current traversed a number of Maxim's incandescent lamps, the changes in the resistance and brightness of the lamps had to be kept in view.

The measurements of the mechanical work were effected by means of an Easton-Anderson integrating dynamometer. To measure the intensity of the light a Foucault photometer was employed. The electrical measurements were carried out with a Deprez galvanometer, with which the total current, and, from time to time, the exciting current were measured; with a Siemens electro-dynamometer, which was employed in measuring the charging currents, and with a graduated electrometer, according to Joubert's method, which was used for determining the difference of potential between the poles of the battery.

The readings of the instruments were at first taken every quarter of an hour, and every $7\frac{1}{2}$ minutes during the later period.

Mean Intensity and Quantity of Electricity.—The mean intensity during a certain time is the arithmetical mean of the intensities taken every quarter of an hour.

The product of the number of seconds, and of the mean intensity in ampères, gives the quantity of electricity generated during the time.

	Mean Intensity.	Seconds.	Coulombs.
4 January	10·930	19800	216400
5 "	7·970	25200	200800
6 "	7·936	27000	214300
7 "	6·360	9900	69000

In order to arrive at correct conclusions, the same cal-

culations have to be made with regard to the exciting current.

	Mean Intensity.	Seconds.	Coulombs.
4 January	2·46	19800	48700
5 „	2·81	25200	72800
6 „	2·33	27000	62900
7 „	2·18	9900	21600

Calculations of the Electrical Work.—As long as the difference of potential between the two poles of the battery remains unchanged, the electrical work employed in charging the battery is equal to the product of the quantity of electricity and the difference of potential, divided by the acceleration due to gravity, g. When this difference changes, each observed intensity has to be multiplied by the corresponding difference of potential, again divided by g, and the arithmetical mean of all the results has to be taken.

In this way were calculated the numbers in columns 8 and 9, Table I., and those in column 5, Table II.

Column 8 gives the electrical work T' spent in conducting the quantity of electricity to the battery, with which the latter was charged.

ELECTRICAL WORK DURING THE CHARGING.

	Difference of Potential.	Quantity of Electricity.	Work.
4 January	82·21	216400	1814600
5 „	91·08	200800	1947100
6 „	92·91	214300	2028800
7 „	92·06	63000	591600
			6382100

Column 9, Table I., shows the work spent in exciting the electro-magnets.

ELECTRICAL WORK FOR EXCITING.

	Difference of Potential.	Quantity of Electricity.	Work.
4 January	82·21	48700	408400
5 ,, ...	91·08	72800	676300
6 ,, ...	92·91	62900	596100
7 ,, ...	92·06	21600	202800
			1883600

Column 10 shows the value of the electrical work T''' in the armature calculated for each day, by multiplying the resistance of the armature, 0·27 ohm, by the square of the total intensity observed in the galvanometer, and multiplied by the number of seconds.

Resistance of the Ring.	Strength of Current.	Number of Seconds.	Electrical Work in the Armature.
0·27	13·29	19800	94400
0·27	10·78	25200	79100
0·27	10.26	27000	76800
0·27	8·54	9900	19500
			269800

When the sum of these different amounts of electrical work has been ascertained, and when to this is added the work of transmission, t, obtained by direct measurement, we find that between this sum and the work T read off from the dynamometer, there is only a small difference of about 2 per cent.

The Electromotive Force and the Resistance of the Battery.—The electromotive force of the battery is given directly by the electrometer, for open circuit. Let E be this value, and e the readings of the electrometer, when the circuit is closed; let R be the resistance of the battery, and F the intensity of the current, then $e = E \pm RF$ according as the battery is being charged or discharged.

As E, e and F are known for the same moment of time, R, the total resistance can be easily found.

During the charging, E varied between 72 to 75·8 volts, that is, between 2·057 and 2·165 for each element; the mean of e was a little below 90 volts, and the mean intensity of the current was 8·55 ampères.

During the discharge E went back from 75·6 to 72 volts; e sank to about 60 volts, with a current of 16·16 ampères.

During the charging, the resistance of each element varied between 0·023 and 0·075 ohm, and between 0·006 and 0·040 ohm, during the discharge; at the commencement of the discharge, the change in direction of the current suddenly caused this resistance to sink from 0·075 to 0·006 ohm.

	Electromotive Force of the Open Battery Circuit.		Resistance of Battery.	
	At commencement.	At end.	At commencement.	At end.
4 January	72·00	75·10	0·80	1·28
5 "	73·10	75·60	1·41	2·32
6 "	72·10	75·50	2·58	2·61
7 "	74·50	75·80	2·61	2·63

Duration of the Discharge.—The discharge took place on the 7th and 9th of January, lasting altogether ten hours thirty-nine minutes. There were 11 Maxim lamps in the circuit. The experiments were commenced with only thirty elements. After six hours two new elements were added, and after about two hours the three remaining elements were added for only a quarter of an hour. During this time the current was too strong for the normal burning of the lamps.

On the first day the discharge experiments were interrupted after seven hours fifteen minutes, and they were

taken up again only the day but one following. After the new discharge had lasted three hours and twenty minutes, the battery was in its original condition.

Electrical Measurements.—The data referring to the total amount of electricity given out were the following:

	Mean Intensity.	Seconds.	Coulombs.
7 January.........	16·128	26340	424800
9 ,, ...	16·235	12000	194800
			619600

The condition of the battery will be seen from the following numbers:

	Electromotive Force in Volts of the Battery, consisting of 33 Elements on Open Circuit.		Resistance of the Battery in Ohms.	
	At commencement.	At end.	At commencement.	At end.
7 January	75·01	—	0·21	0·25
9 ,,	72·50	72·00	0·26	1·41

Resistance of the Lamps.—If by r we denote the resistance of the external circuit during the discharge, we obtain $e=E-R\ F=r\ F$, from which expression, the value of r can easily be found; for the value of e and F can be ascertained at each moment, by observation.

Photometric Determination.—With regard to the expenditure of work per second per Carcel-burner (7·4 candle power), it is affirmed in the article in "La Lumière Electrique" from which these data are taken, that this work has a value of 8 kgrs.-mm. This, however, does not agree with the statement that on an average each Maxim lamp represented an illuminating power of 1·40 Carcels (10·36 candles).

Taking this statement as a basis, we obtain, if the average intensity of light during ten hours thirty-five minutes is 1·40 Carcel-burners, a value equal to that of 163·9 Carcel-burners power during one hour.

Now, from Table II. we see, that as the whole of the electrical work done by the battery was equal to 3,809,000 kgrs.-mm., each Carcel-power per hour cost $\frac{3809000}{163 \cdot 9}$ (=23,229) kgrs.-mm. per hour, or 6·4 kgrs.-mm. per second.

Conclusions.—From a comparison of the data given in the foregoing tables, we immediately perceive that of the quantity of electricity equal to 694,500 coulombs, stored in the battery, 619,600 coulombs were returned during the discharge. Accordingly, there was a loss of 10·8 per cent. only.

With regard to the work expended and returned, Table I. shows that the mechanical work spent corresponds to 9,570,000 kgrs.-mm.; of this only 6,382,000 kgrs.-mm. were stored; and 3,809,000 kgrs.-mm. of this store could again be used during the discharge; that is, $\frac{3809000}{9670000}$ (=0·40) of the whole work expended, and $\frac{3809000}{6382000}$ (=0·60) of the work stored.

The final result of the experiments can accordingly be stated thus:

The charging of the battery required the expenditure of 1·558-horse power of mechanical work during a period of 22 hours 45 minutes (=1,365 minutes), and this corresponds to an expenditure of work of one-horse power during 1·558 × 1,365=2,126 minutes =35 hours 26 minutes; 44 per cent. of this work was lost through passive resistance and in the work of exciting the generator, and only $\frac{6382000}{9670000}$ (=66 per cent.) was really employed in the charging of the battery.

Of the 6,382,000 kgrs.-mm., however, which were stored

in the battery, only 60 per cent. were effective in the external circuit during the discharge.

Accordingly, in employing the Faure battery to supply the electric lamps, instead of directly using the dynamo-electric generator, 40 per cent. of the work given out by the generator was lost. We thus see that the secondary battery is by no means an economical apparatus, and that the convenience offered by its use has, according to these results, to be paid for pretty dearly. Nevertheless, in making the external circuit independent of the electric generator, and the generator independent of the electric circuit, the secondary batteries render invaluable service; and apart from the fact that doubtless in time the construction of these batteries will be so improved that a much smaller loss of work will accompany their employment, they are even now of great value in practice in those cases where the working power, and consequently the production of the electric current is cheap.

A very great improvement in storage batteries is due to **Mr. Swan**, and to **Messrs. Sellon and Volckmar**. One of the great defects of the Faure accumulator is the interposition of the felt; and in fact any porous separator by adding to the internal resistance of the battery more than proportionally reduces the economy. In practice also, the lead-oxide became detached from the plates, and fell to the bottom of the parchment paper bags or covers, causing these to bulge out into contact with the bag or cover on the opposed plate; a short circuit was therefrom frequently established in a cell. Messrs. Swan, Sellon and Volckmar introduced a grid, or perforated plate, into the holes of which the red lead paste is forced and there held. The plates are then separated by rubber stops, and immersed in the usual solution of dilute acid.

These plates are about $\frac{1}{8}$ of an inch in thickness and 10 inches square. Fourteen pairs give $1\frac{1}{2}$ electrical horse-power hours in actual use. A great advantage has accrued from thus dispensing with the felt and with the danger of detachment of the lead-oxide from the plate; whilst in consequence of expansion during the formation of per-oxide, the red lead paste becomes very firmly gripped by the surrounding grid-work. Mr. Sellon has, however, several patents for bevelling the edges of the holes so as to hold in the paste, an improvement that it does not appear necessary to put into practice.

Having made, at the Stevens Institute of Technology, tests and measurements of the Sellon-Volckmar electrical storage batteries sent to him, and manufactured by the Electrical Power Storage Company, Professor Henry Morton found the following results in reference to their capacity to store and retain energy, afterwards delivered by them as electric current.

The cells were of the pattern called "one-horse power" cells, because they contain, when fully charged, an amount of energy equal to 1,980,000 foot-pounds, or one-horse power for one hour.

These cells were externally rectangular wooden boxes, $12\frac{1}{2}$ inches high, $11\frac{1}{2}$ inches wide, and $5\frac{3}{4}$ inches thick.

Two of them, side by side, as they would stand when in use, occupied about one cubic foot of space.

Each cell contained sixteen plates, whose united weight was 48 lbs., and with the lead-lined box and liquid, the entire weight of the cell, when in use, was $79\frac{1}{2}$ lbs.

One of these cells fully charged gave, as found by careful experiment, a current of 32·5 ampères at the beginning, and 31·2 ampères at the close of a continuous discharge for nine hours.

This amounts to 286·5 ampère-hours of current, and if even short interruptions or periods of repose occurred in the use of the current, a larger total amount could be obtained.

An Edison incandescent lamp of high resistance, giving a light of 16 candles, requires a current of ·73 of an ampère to supply it. Such a current, therefore, as these batteries gave for nine hours at a time sufficed for 44 such lamps.

To secure sufficient electromotive force or propelling power to overcome the resistance of these lamps would, however, require about 50 of such cells. So that a battery of 50 of these cells connected in series, would operate 44 lamps for nine hours, or for even a longer time in the aggregate, if the use were interrupted, as it would be in practice.

If fewer lamps were used with the same battery they would be operated for a proportionately longer time.

Thus, 11 lamps would be supplied by a 50 cell battery for thirty-six hours of continuous action; or, as lights are commonly used in private houses on the average for five hours each night, such a battery once charged, would operate 11 lamps for a week.

To express the relation between weight of battery and power of maintaining a light, we may therefore say that for each lamp operated for nine hours $1\frac{1}{7}$ cells of battery would be required, or a weight of about 90 lbs. of battery. This would be for each hour of burning each lamp, 10 lb. of battery.

This makes a very simple rule for calculating the weight of battery required for any number of lamps for any time.

Thus, suppose we wish a battery to operate 25 lamps

for five hours each night, the battery being recharged during the day. We have $25 \times 5 \times 10 = 1{,}250$ lbs. as the weight of battery required. Comparing the efficiency of this storage battery with that of other similar arrangements, such as the Faure battery, measured and reported upon by M. Tresca, of the Conservatoire des Arts et Metiers, it shows a marked superiority.

Thus, in M. Tresca's experiments, a cell weighing 95 lb., yielded a current representing 793,791 foot-pounds of energy where this battery yielded 1,826,168 foot-pounds, and only weighed 80 lb.

Even the experiments made by Professors Ayrton and Perry, on other Faure accumulators, though the conditions were rendered as favourable as possible, by distributing the discharge over three periods of six hours each on three successive days, do not show a much better result. In this case the weight of the battery-plates only is given, and that is eighty-one pounds. Reducing the results proportionally for batteries whose plates weigh forty-eight pounds, Professor Morton has found that by the experiments of Professors Ayrton and Perry, each cell of this weight should give 853,333 foot-pounds of energy.

This, again, is less than half the amount of energy recently repeatedly obtained.

Passing next to the efficiency of the batteries, as regards their delivery of nearly the same current as was used to charge them, Professor Morton found that the loss in this relation is less than ten per cent. In other words, he has obtained from these batteries ninety to ninety-one per cent. of the current used to charge them. This far exceeds the results obtained by M. Tresca, or by Professors Ayrton and Perry with the Faure batteries.

Tresca reports that he recovered only sixty per cent. of the current used to charge the battery, and Ayrton and Perry found the loss in charging and discharging to be "not greater than eighteen per cent.," and in some cases of very slow discharge, to be only ten per cent.

Professor Morton found the loss to be less than ten per cent., with a rapid discharge of thirty-two ampères.

Lastly comes the very important question as to the retention of charge during a long time. To test this, three cells were charged, and locked in a closet, where they remained fifteen days, when at the rate of thirty-two ampères, there were obtained 266·7 ampère-hours of current.

Comparing this with the 286·5 ampère-hours of current obtained from the other cells discharged soon after charging them, shows a loss of seven per cent. caused by standing for sixteen days.

The above measurements and comparisons show that this storage battery has attained a degree of efficiency which will render it applicable to a number of uses.

Thus, Professor Morton suggests that on steam-boats, by the use of such storage batteries, the irregular and occasionally interrupted motion of the main engine might operate a relatively small dynamo-electric machine, so as to charge the batteries during the entire twenty-four hours, and the current from these batteries would then supply light, with perfect steadiness, during the relatively brief time in which it is required. In this way, the cost of supplying and running a special and large engine, which would be needed for operating the same lights directly without the storage battery, would be avoided, and also the necessity for extreme steadiness in running the dynamo, and all risk of extinction of the lights from a

momentary interruption of motion in any part of the machinery would be removed, as the battery would secure an absolutely steady and continuous supply of current, no matter how little regular might be the action of the engine or dynamo-electric machine.

Again, in larger buildings, the engine used to operate the elevator or lift, or to do any other work, if of sufficient power, could charge the storage battery without interrupting its regular work, and thus supply the light needed at a minimum cost for special machinery and skilled supervision.

In private houses, where the running of a large engine with extreme smoothness and absolute certainty during the hours when light is needed, would be out of the question, a small engine, operated at convenient intervals, and with no need of regularity or of fixed hours, would accomplish all that was required, if a storage battery was employed with it.

Mr. C. F. Brush, the inventor of the well-known system of arc lighting bearing his name, has carefully investigated the chemical and mechanical action involved in the process of formation, and has arrived at a satisfactory explanation of the results produced.

The formation of peroxide of lead on one of the plates continues indefinitely as long as the exciting current is maintained, becoming constantly slower as the metallic surface acquires an increasing protection against further action by the constantly increasing thickness of the coating of peroxide.

Peroxide of lead being a good conductor of electricity, the coating becomes a part of the conducting-plate or element of the battery, and free oxygen is evolved at the surface of the coating. Now, if the exciting current be

stopped, "local action," somewhat similar to that in galvanic batteries, and electrical in its nature, commences between the peroxide of lead and the backing or support of metallic lead with which it is in contact. By this "local action," the peroxide of lead is gradually reduced to a lower state of oxidation, while more of the metallic lead of the plate is oxidised by the oxygen thus made available.

The fresh lead thus oxidised doubtless acquires the same condition of oxidation that the original peroxide finally assumes. But the peroxide is never by this action reduced to the state of protoxide, as is proven by the colour of the coating, and the non-action on it of the ever present sulphuric acid.

When peroxide of lead is thus reduced to a state of lower oxidation, it becomes useless for the development of a secondary current until freshly charged or re-oxidized. Thus is explained, so far as the oxygen plate is concerned, the cause of the gradual loss of charge observed in lead secondary batteries.

Further, since the conducting power of peroxide of lead rapidly decreases as its oxygen is removed, the reason of the high electrical resistance of the oxidized plates after long standing uncharged is also explained. When such a plate, that is, one having gradually lost its original charge by local action, is re-charged by an electrical current as at first, it will hold a larger charge than before; because all of the lower oxide of lead is now raised to the condition of peroxide, and thus more of the latter is present than at the previous time of charging. This explains why the oxygen plate of secondary batteries constantly increases in capacity, even though the exciting current be applied at long intervals.

Let us now consider what takes place at the opposite side of the secondary battery, that is the action on the lead plate where the hydrogen appears. Here the hydrogen is absorbed at the surface of the plate, being simply occluded, or more probably forming a definite but feeble chemical combination with the lead. If such a combination exists, it is a nearly or quite stable one, so far as "local action" is concerned, for experience shows that the capacity of the plate for the reception of hydrogen increases very slowly, if at all, when the plate is left charged a long time, but without the action of the exciting current; even the continued action of the exciting current increases the capacity of the hydrogen plate very slowly indeed, as compared with the improvement of the oxygen plate during the same time.

The capacity of the hydrogen plate never becomes at all considerable when it is subjected to the above action alone. Hence, in practice, the oxygen plate soon acquires much greater capacity than the hydrogen plate; but this is of no advantage, since its usefulness is limited by that of the hydrogen plate. But if now the charge of the two plates be reversed, by changing the direction of the exciting current, the former hydrogen plate will absorb oxygen freely as did the other plate at first, while the former oxygen plate will have its coating of oxide of lead reduced to the metallic state of the nascent hydrogen evolved upon it, and will thus be left with a corresponding coating of porous lead. This porous metal is now in a condition to absorb and retain an amount of available hydrogen, about equivalent to the available oxygen which it before held.

Thus it will be seen that the simple act of reversing the charge of the two plates increases the capacity of the

apparatus up to a point attained only by the oxygen plate before the reversal. Again, what is now the oxygen plate continues to improve, as in the first instance, while the hydrogen plate remains nearly or quite stationary in this respect.

Hence, after a time, a further increase of capacity in the apparatus may be affected by another reversal. Thus is explained the reason for the many reversals of charge customary in " forming " the plates.

When a previously excited secondary battery is discharged, the peroxide of lead is reduced to a state of lower oxidation, as already explained in connection with the spontaneous loss of charge. Thus, what was at first a good conducting coat on the metal, is now reduced to a poor conductor, as previously explained, while at the same time pure water is formed within the mass of lead oxide by the combination of hydrogen with a portion of the oxygen of the peroxide of lead; and, since pure water is a very poor conductor of electricity, a further barrier to the passage of current between the sulphuric acid solution and the metallic plate within the envelope of lead-oxide is raised.

These two causes (lower oxidation and presence of pure water) account, so far as the oxygen plate is concerned, for the increase of resistance in secondary batteries during their discharge, and especially toward the end of the process.

In the case of the hydrogen plate, pure water is also formed by the union of oxygen with its hydrogen, whereby the necessary liquid conductor within the porous metal has its resistance largely increased.

The cause of the gradual spontaneous loss of charge, in case of the hydrogen plate of secondary batteries, is not the same as that already described in connection with the

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oxygen plate. The hydrogen in this case seems to be gradually dissolved and carried away from its plate by the dilute sulphuric acid, which then discharges it gradually into the atmosphere.

If, in charging a hydrogen plate, a chemical component of lead and hydrogen is formed, this compound would appear to be gradually decomposed in the presence of the acid water, giving up its gas to the latter.

There are certain evils incident to the above-described process of "forming" the lead plates of secondary batteries, which attendant evils prevent the attainment of the best results and limit the ultimate capacity of the apparatus to a comparatively small field of usefulness.

The coating of peroxide of lead which is formed on one of the plates, necessarily occupies more space than did the metallic lead which it contains. The shell of oxide must then expand in forming. To accommodate this expansion, which evidently occurs in all directions, the structure of the deposit must be more or less broken up at numerous points, or else the lead plate itself must expand. The occurrence of the latter action may be readily observed when the lead sheet is thin. When, now, the direction of charge is reversed, by which operation the oxide of lead is reduced to the metallic state, the previously-expanded mass shrinks. Both the expansion and subsequent shrinkage may be illustrated by treating one side only of a sheet of lead, the other side being protected from action by varnish, or otherwise. When such a plate is oxidized, the exposed side becomes convex; when the oxide is subsequently reduced, this side becomes concave.

During the process of reduction the shrinkage does not occur in all parts of the mass at once, as the reduction is not simultaneous in all parts at once, but is progressive.

The converse of this is true when the reduced lead is again oxidized. Hence there is a disintegrating action in the changing mass itself, as well as between it and the solid plate behind it. This alternate expansion and contraction of the active and valuable portion of the lead plate does not lead to serious disturbance when it is allowed to occur only once, or a very small number of times. But if these changes are many times repeated, the coating peels off from the lead plates to a considerable extent, and thus becomes useless. This evil is especially noticeable in the case of thick deposits.

Again, every time the deposit of oxide of lead is reduced, a notable quantity of sulphate of lead is formed within the mass. This inert and useless substance, when allowed thus to form, soon exercises a very deleterious influence, wasting in its formation the otherwise available oxide of lead, stopping the pores of the essentially porous mass, and tending to disintegrate the latter by occupying a much larger space than the oxide of lead from which it is formed.

The reduction of the oxide of lead is also attended with danger of separating the mass from its supporting lead plate, by the liberation of gas between the two, especially when the reducing current is of sufficient strength to effect the change at all rapidly.

The frequent reversal of charge is also expensive, in that much energy of charging current is wasted at each operation.

Further, it will be seen that the oxygen, which is the active though slow agent in improving the plates, acts not on both plates simultaneously, but on only one at a time.

The method or process of "forming" the plates or

elements of secondary batteries, which has been adopted by Mr. Brush, has been so adopted with a view to avoid or eliminate these evils enumerated almost entirely.

The process consists in charging the plates which are ultimately to constitute the battery in such a manner that a coating of peroxide of lead of sufficient thickness is formed on both of them; these plates are then associated together in the usual manner, and an electric current passed through the apparatus in the manner customary in charging; one of the plates remains unchanged, and constitutes the oxygen element of the battery, while the other has its charge reversed, and now constitutes the hydrogen element of the battery.

The plates, while acquiring their coating of peroxide of lead, may, for this purpose, be charged continuously; or, equally effective and more convenient, they may be charged at intervals only, short at first, which may be increased in length as the process progresses, thus allowing the local action between the peroxide of lead already formed and the metallic lead to continue the oxidizing process during the time the changing current is not acting.

Several months of continuous or intermittent charging is required when ordinary sheet lead alone is employed for the plates, in order to produce a satisfactory coating of peroxide of lead.

This process of "forming" the plates of secondary batteries, is applicable not only to the flat or plain plates ordinarily used, but equally so to corrugated and to ribbed, honeycombed, perforated, slotted, or otherwise fashioned plates, also to plates coated or filled with spongy or porous, or reduced lead.

Another of Mr. Brush's improvements consists in pro-

viding the plates with a suitably thick coating of electrically-deposited coherent metal previous to the process of "forming."

In coating the plates, the coherent porous lead is deposited by electrical action as in any ordinary process of electro-plating; the plates to be coated first being made chemically clean, and the plating solution consisting of oxide of lead dissolved in a solution of a caustic alkali, or of an equivalent solution of lead. Any solution of lead may be used, provided it is such as to produce a coherent deposit of metal, and not a spongy or non-coherent deposit. The latter kind of deposit is always produced when the sulphate, chloride, acetate, nitrate, and some other salts of lead are reduced electrically, and possesses properties different from those of the coherent form of metal; being vastly inferior to the latter in efficiency as a material for secondary batteries.

The coherent metal may be deposited with greater or less rapidity as may be found most expedient or desirable in practice, the character of the deposit varying to some extent according to the rate and other circumstances of its formation.

Corrugated or perforated plates are well adapted to receive and retain the coherent coating, and the corrugations or other spaces or cavities in the plates may be entirely filled with the deposit if desirable. When such plates are treated to a deposit of coherent lead in the manner customary, the interior of the cells or cavities or corrugations will receive a less heavy deposit than the more exposed portions. This difficulty is avoided by adopting the following method of working:

The plate being first thoroughly cleaned, has the grooves or cavities on one of its sides filled with pro-

toxide or other suitable compound of lead, either dry or made into a paste with water or saline solution.

The plate is then placed horizontally, prepared side up, in a suitable vessel containing a solution of caustic soda or potassa, or other alkali, when protoxide of lead is used in the grooves.

In the same solution, but not touching the plate, is suspended or placed a lead or equivalent plate. Current is then passed through the apparatus in the proper direction until the lead-oxide in the grooves or corrugations is exhausted, and its metal deposited on the sides and bottom of the grooves. More lead-oxide is added if it is desired to increase the deposits.

Plates of other metals than lead might be employed to receive and support the deposited lead; thus, if gold or platinum were used the oxygen element of the battery, if fully peroxidized, could not lose its charge by spontaneous "local action."

When lead plates coated with deposited coherent lead are associated together in a secondary battery and charged, the reduced metal is peroxidized much faster than ordinary cast or rolled lead, but not nearly so fast as spongy or non-coherent lead; while the coherent lead of the other plate absorbs hydrogen more freely than cast or rolled lead, but not nearly so fast as the other plate of the battery absorbs available oxygen.

It becomes advisable, then, to resort to a "forming process."

The plates of secondary batteries can be provided with a suitably thick coating of porous metal, reduced from the oxide, through the agency of a suitable reducing gas, and at a temperature insufficient to cause the reduced metal to assume a compact or fluid condition through fusion.

Either of the gases, carbonic oxide or hydrogen, will do this readily. The plates having been made chemically clean, are placed in a horizontal position and covered to a sufficient depth with lead oxide. This is applied preferably in the form of a paste, with nitric acid, which partially dissolves the oxide, and when evaporated leaves the latter in a coherent compact condition.

After the plates are coated with oxide, they are packed, sufficiently separated from each other, in a chamber, where they are raised to a high temperature, and exposed for a sufficient length of time to the action of a reducing gas.

Mr. Brush also proposes to construct the plates of metallic lead in a pulverised or finely-divided state, and to allow the surface of the lead particles to become oxidized, either by exposure to the air, or by any artificial oxidizing process.

Or, instead of employing the superficially-oxidized particles of lead as above specified, to take particles of metallic lead and oxide of lead and effect a thorough mechanical mixture of the two.

In either of the above cases, lead and lead oxide are thoroughly intermingled, and, under heavy pressure, the particles are consolidated into a compact mass.

The mass thus formed consists of metallic lead having minute veins of oxide of lead everywhere ramifying and extending through it; and these veins of lead oxide within and throughout the mass greatly facilitate the penetration of the electrical action in "forming" the plates for operative use in secondary batteries.

Applications of Secondary Batteries.—The special applications of secondary batteries can be classed under two headings, according as we wish to use the battery

as a fixed electrical reservoir, or as a portable vessel charged with electrical energy.

As a fixed reservoir, these batteries can be used, even in their present incomplete condition, in all cases where a uniform, continuous current is absolutely necessary for the work to be done; and the loss of work will then be counterbalanced by the steady results obtained, for the secondary batteries are undeniably excellent regulators. If, for instance, instead of supplying a circuit directly from an electric generator, we do so aided by a secondary battery connected with it, then, however irregularly the generator may work, there will always be a uniform current in the circuit; and, similarly, no variations in the circuit will, in this case, affect the working of the generator.

If, however, it is desired to make use of the secondary batteries, in their present form, as portable vessels, charged with electricity, it will only be possible to employ them with real advantage when a comparatively small number of elements have to be transported. The great weight of the batteries, which for the most part consist of lead, is a considerable obstacle to this use; for, in many cases, the cost of carriage will annul the advantages offered by the battery.

If the advertisements of the "Société la Force et la Lumière," in Paris, could be trusted, or even if Reynier's statements had proved correct, we should be led to suppose that the results obtained with the Faure batteries would be but little influenced by the weight of the apparatus; and, two years ago, some persons went so far as to assert that it would pay to send batteries charged with electricity to the houses of the inhabitants of a town. After use, the exhausted batteries were to be replaced by

those freshly charged, somewhat in the way that is done with bottles of beverages.

However, on a little calm reflection, and by making the data obtained in the experiments given above the basis of decision, it will be seen that lead-batteries can find only a limited application as portable accumulators.

According to Reynier's statements, a Faure's element, weighing 8 kg., gives out work at the rate of 4·4 kgrs. m. per second; that is, 0·55 kgrs. m. to each kg. of weight; the data obtained by the French committee, however, showed that the thirty-two elements, of which each weighed 43·7 kg., and whose total weight accordingly came to 1398·4 kg., stored 6,382,000 kg. m. of work; and during the discharge, which lasted ten hours thirty-nine minutes, they gave out 3,809,000 kg. m. of work. So that, during this time, $\frac{3809000}{1398} = 2,725$ kg. m. corresponded to each kilogram of weight; and $\frac{2725}{38340} =$ 0·071 kilo. to one kilogrammetre per second; that is, the work given out per kilogram of the battery, only constitutes an eighth (7·7th) part of the value stated by Reynier.

If it were intended, for instance, to employ a Faure battery for the purpose of setting an electric railway in motion, and if we assume that the elements are to work during ten hours thirty-nine minutes (this is, perhaps, rather a long period, considering the object, but we shall retain it in order to make use of the data given above), it is easy to determine the efficiency of the battery per kilogram of weight. We will assume that the speed of the train is to be ten kilometres an hour (equal to three metres per second), and that the coefficient of friction is that usually taken in the case of railways on which the rails are good, and are kept clean—namely, $\frac{1}{240}$.

In this case, a force of $\frac{3}{240}$ kg. m. = 0·012 kg. m. would be necessary to make one kilogram move with a velocity of three metres per second. Now, as each kilogram of the battery, as we have seen, is able to do 0·07 kg. m. of work, it will be able to pull five kilos., besides its own weight.

This rather favourable result, however, only refers to the case when the secondary battery is used to move carriages that run on smooth, clean rails. If the battery is to be used for tramway carriages, which have to run on rails in whose grooves dirt accumulates, and where accordingly the friction is comparatively great, the coefficient of friction is much more unfavourable, and it can be denoted by about $\frac{1}{100}$.

In this case, therefore, the moving of a kilogram would require 0·03 kgr. m. to be exerted, if the carriage is to travel ten kilometres per hour; accordingly a battery giving out 0·07 kilogrammetres of work per kilo. would not be able to set double its weight in motion.

It is evident, therefore, as constructed at present, secondary batteries offer comparatively few advantages as portable accumulators; and if it is desired to employ such batteries in carriages, it will be better to limit the number of elements as much as possible, and to recharge them more frequently, instead of carrying a large number.

When the secondary batteries are to be employed in the lighting of railway carriages, the axle of a carriage can be connected with a dynamo. During the journey, the secondary battery will be charged by the current, and from it the lamps will be supplied. The latter will continue to burn steadily, even when the train stops, being only indirectly connected with the electric

generator. In this way many applications of secondary batteries will be found, and it will always be possible to make good use of them, if it is not forgotten that the weight of the battery has to be kept as low as possible when there is any question of moving it.

CHAPTER VI.

THE PHYSICAL LAWS BEARING ON THE CONSTRUCTION OF ELECTRIC MACHINES; AND THEIR APPLICATION IN PRACTICE.

In the previous chapters we gave to some extent a summary of what has been done in electro-technology as relates to magneto and dynamo-electric machines and their auxiliary apparatus; and the reader will have gathered that the results achieved are extremely encouraging.

Nevertheless the construction of electro-generators is still in its infancy, and many improvements will have to be carried out before the manufacture will have reached that stage it must undoubtedly attain. Accordingly, in a book such as this, intended for the use of technologists, it will be necessary to discuss those theoretical principles on which depends the efficient construction of an electric generator.

It may be objected that as a rule the theoretical electrician considers cases which only occur in practice with great modifications. Nevertheless the conclusions of the physicist can be easily modified for practical application if the cases on which they are based are accurately compared with those under consideration, and when the differences are accurately taken into account. It ought not to be forgotten that, although theory does not always put means into the hands of the practical man to carry

out his problems, it, at any rate, points out the way by which these means can be found, and thus saves the constructor much time and trouble, which he would otherwise often spend unsuccessfully in trying to find an answer empyrically to the questions that come before him. Consequently, before we pass to the various details of construction we shall try to develop briefly the principal physical laws that affect the construction of an electro-generator.

These laws specially bear on the following points:

(1). The relation of the electromotive force of a generator to the work to be done.

(2). The ratio of the internal resistance of a generator to the resistance in the external circuit.

(3). The interdependence of the electromotive force and quantity of current:

(*a*) on the number of convolutions in the armature;
(*b*) on the rate of rotation of the armature;
(*c*) on the intensity of the magnetic field in which the armature moves.

To commence by considering the first point, and to try to get an answer, by theoretical methods, to the question:

I. What must be the ratio of the electromotive force of a generator to the external work done, in order to obtain maximum effect?

For this purpose we will assume that an electro-generator is to be used for obtaining galvano-plastic deposits, and that we know the resistance of the galvano-plastic bath and of the generator.

Let E be electromotive force of the generator, R the total resistance that the current has to overcome, and I the quantity of current. Then from Ohm's law we have,

$$I\,R = E. \tag{1}$$

Now, if, instead of the galvano-plastic apparatus we, for the present, insert an insulated conducting wire having exactly the same resistance, a quantity of heat will be evolved, when the current traverses the wire, corresponding to a definite amount of work L, and according to Joule's law this work is

$$L = E \,.\, I = \frac{E^2}{R}. \tag{2}$$

Now, when, instead of the substituted resistance, we insert the galvano-plastic bath, it might be supposed from a superficial consideration, that the quantity of current would be the same, because the resistance had remained unchanged. This however is not the case; the quantity of current diminishes, for it is partially annulled by an opposing electromotive force arising in the bath during the work. We will denote the new strength of current by I' and putting t for the time during which we obtain as large a quantity of electricity from the generator, as we did in unit time when the corresponding resistance was inserted in place of the galvano-plastic bath, we shall have

$$I = t\, I'. \tag{3}$$

That is, in unit time, only the part of the effective electrical energy is converted into real work l, that corresponds to the quantity I', whilst the remaining portion, which we will call L', is distributed in the circuit as heat.

Now, because the current is proportional to the work (or to the corresponding amount of heat), we obtain from equation (3)

$$L = (L' + l)\, t \tag{4}$$

Eliminating t, in equations (3) and (4) we get

$$\frac{L}{I} = \frac{L' + l}{I'}. \tag{5}$$

The reason why only part of the current is converted

into work, whilst the other part manifests itself as heat, has to be sought in the existence of the opposite electromotive force which we shall call e.

In this case we get

$$I' = \frac{E - e}{R}; \; L' = \frac{(E - e)^2}{R} \tag{6}$$

and from equations (5) and (2)

$$E = E - e + l \frac{R}{E - e}$$

or
$$l\,R = e\,(E - e). \tag{7}$$

Now, writing $e = R\,i$, where

$$i = I - I'$$

we get from equations (7) and (1)

$$l = R\,i\,(I - i) = R\,i\,I'$$

and as it follows from equation (1), that

$$L = I^2\,R$$

then putting x and y for the quotients $\frac{i}{I}$ and $\frac{I'}{I}$ respectively, we get

$$x + y = 1\,; \; x\,y = \frac{l}{L}.$$

Consequently as x and y are the roots of the quadratic equation

$$z^2 - z + \frac{l}{L} = 0$$

it follows that
$$z = \frac{1}{2} \pm \sqrt{\frac{1}{4} - \frac{l}{L}}.$$

It becomes evident, therefore, that the ratio $\frac{l}{L}$ can never be greater than $\frac{1}{4}$; that is, when the current has no other work to do, and has only to overcome the internal and external resistance, $\frac{1}{4}$ only of the electrical

energy can be converted into another form of energy (in our case, into the work of chemical decomposition).

When this maximum of the conversion of electrical energy into work is reached

$$i = \frac{1}{2} I;\ I' = i;\ e = \frac{1}{2} E;\ t = 2,$$

or, the quantity of current, and the electromotive force are only half as great as when the current has no other work to do, the resistance being the same; and from this follows the important principle:

The efficiency of an electro-generator is greatest when its electromotive force is twice as great as the opposing force that arises whilst the current is doing work.

In the case we have taken, where the generator is intended for galvano-plastic purposes, the electromotive force of the current ought to be twice as great as the opposite electromotive force generated in the galvanic bath by polarization.

The same principle also holds good when the generator is employed to do dynamic or magnetic work, but has to be modified when the generator is intended for illuminating purposes.

Although in the case of the luminous arc, Edlund discovered that an electromotive force is generated by the polarization of the electrodes, and acts counter to the electromotive force of the generator, yet it does not behave otherwise than as a resistance of the circuit. Both generate radiant energy, and where the resistance of the arc is great, as compared with the electromotive force due to polarization, the preceding law for the greatest efficiency loses its importance.

In practice we have to see that we get as much energy as possible in the external circuit, and this is attained by

making the internal resistance of the generator as small as possible.

In fact we have in practice to modify the theoretical law thus: the electromotive force of the generator shall be always greater than the opposing electromotive force that arises.

The question bearing on the second point mentioned at the beginning of this chapter would be—

II. What internal resistance is best, in order to obtain the greatest efficiency with a given external resistance?

The answer to this question can also be found by a theoretical method.

We will assume that an armature has n armature-coils, all having the same resistance and the same electromotive force, and the question is how are we to couple up the bobbins so as to make the greatest possible use of the current of the generator.

For this purpose let n be the number of armature-coils, e the electromotive force, and r the resistance of each. The total electromotive force of the armature will accordingly be ne, and its resistance nr, when the bobbins are coupled up in series.

If the coils, however, are coupled up for quantity, or if their similar poles are connected, then the electromotive force of the armature will only equal that of a single bobbin, namely e, but the internal resistance will be equal $\frac{r}{n}$.

The coils can also be arranged in groups. The elements of each group can be coupled up for quantity and the groups themselves for intensity.

When each group contains the same number of similar elements, this mode of connection corresponds to a like arrangement of a voltaic battery.

Let x be the number of elements in a group, e the electromotive force of each group, and $\frac{r}{x}$ its internal resistance. Accordingly, we can express the electromotive force of the whole armature by $\frac{n}{x}$ e, and its internal resistance by $\frac{n}{x} \times \frac{r}{x}$.

Now, the problem is to determine x in such a way that the current generated in the n armature-coils shall attain its maximum in the circuit.

If R represents the resistance in the external circuit and y the current which we obtain when we have made $\frac{n}{x}$ groups out of the number of armature-coils, then from Ohm's law we have the equation

$$y = \frac{\frac{n}{x} e}{R + \frac{nr}{x^2}}$$

or

$$y = \frac{n\,x\,e}{x^2\,R + nr},$$

Hence

$$x^2\,Ry - n\,x\,e + nry = 0 \qquad \text{and}$$

$$x = \frac{1}{2\,y\,R}\left[n\,e \pm \sqrt{n^2\,e^2 - 4\,nr\,R\,y^2}\right]$$

Of course as we have not to deal with imaginary values we may put

$$n^2\,e^2 - 4nr\,R\,y^2 = 0$$

in order to obtain the maximum value for y.

Consequently

$$y = \frac{e}{2}\sqrt{\frac{n}{r\,R}}$$

and

$$x = \sqrt{\frac{rn}{R}}, \text{ or } \qquad R = \frac{nr}{x^2}.$$

Therefore, the maximum efficiency of an electro-generator is obtained when its internal resistance is equal to the resistance in the external circuit.

In practice, however, this law of the maximum theoretical efficiency has to be modified. Although this is the best way of obtaining the greatest amount of work with the generator, yet in practice the object is (for instance, in electric lighting) to obtain the largest amount of work in the external circuit. This, however, would not be the case if the internal resistance of the generator were equal to that of the external circuit. In this case, because as much of the effect is lost in the internal circuit, through heating, as is gained in the external circuit, only 50 per cent of the electrical energy is employed in the latter. For practical purposes this is far too little, and as Uppenborn has pointed out, the internal resistance ought never to be greater than $\frac{3}{7}$ of the external resistance.

We now come to the question

III. In what way does the number of convolutions in the armature affect the strength of current and the electro-motive force of a generator?

This question would, for instance, obtain if we had to construct a magneto-electric generator, in which we had ascertained the intensity of the magnetic-field, and where we wished to work at a constant velocity; with reference to which however we desired to know how many turns of wire we must wind on to the armature in order to get the maximum effect.

The answer to this question is given in the principle established by the law of Lenz and Jacobi.

This law says: With a constant intensity of the magnetic-field and a constant rate of rotation, the

electromotive force of a generator is directly proportional to the number of windings and is quite independent of their radii, as well as independent of the thickness and the specific conductivity of the wire.

However, each new turn of wire or each new layer of turns wound on the armature not only increases the electromotive force of the generator but has its definite resistance, which depends on the length and diameter of the wire, and this has to be taken into consideration in the construction.

If the groove which receives the coil is rectangular in section, all the turns in the same layer are of the same length, and this varies from layer to layer by a constant quantity. Consequently, the armature rotating at a constant rate in a magnetic-field of constant intensity, may be regarded as a series of electro-generators connected in series, their electromotive force being the same, and their total resistance being a multiple of m. In determining the number of turns, and layers of turns, and the thickness of wire, we must get the internal resistance of the circuit into a practically useful ratio to the external resistance. Once this ratio is fixed, it is easy to calculate the number of turns and layers by putting ne for the electromotive force, and $n\rho$ for the internal resistance of the generator, whilst for ρ we substitute the expression $\frac{4\ k\ C}{\pi\ x^2}$, where k represents the specific resistance of the wire, and C the mean length of a wire turn, which depends on the shape and dimensions of the armature.

The thickness of the insulating coating can be denoted by a, in which case the thickness of the insulated wire is $= x + 2a$, and the normal section of the groove which receives the coil must accordingly have an

area $= n\ (x + 2a)^2$ and a capacity $= n\ C\ (x + 2a)^2$; from these two values the two dimensions of its cross-section can be got.

Further, by dividing the height by $x + 2a$, we get the number of layers, and dividing the width by the same value, we get the number of turns that ought to be in a layer.

If the armature is to have several coils, it is best to arrange them so that they can be coupled up for quantity or intensity, and the calculation of their mode of action is then effected as previously described.

The next question which arises in practice is:

IV. What relation has the current and electromotive force of a generator, in whose armature there is a given number of turns of wire, to the rate of rotation of the armature; the intensity of the magnetic-field being constant?

The answer is: We may assume that if the intensity of the magnetic-field and the resistance are both constant, the current will increase in direct proportion with the rate of rotation of the armature.

Accordingly, if the real influence of the speed of a generator is to be known, we have to determine the increase of the resistance.

For this purpose the fact has to be taken into consideration in the calculation that the heat generated in the coils of the armature increases with the current in proportion to the square of the electromotive force, and also in proportion to the square of the rate of rotation of the armature, and that with this, the temperature and resistance of the coil increases. In practice we may also assume that the absolute temperature of the wire increases proportionally to the square of the number of revolutions per minute of the armature. In what way the resistance

of the wire increases with the rise of its absolute temperature can then be calculated from Siemens' formula

$$r = aT^{\frac{1}{2}} + \beta T + \gamma$$

when the coefficient of resistance at 0° C. is known for the metal employed. In this formula T denotes the absolute temperature of the metal ($273° + t$), and r the resistance. The values for the coefficients a β γ are to be obtained from the following table; the formula is calculated for Siemens' units, and for wires 1 m. long and of 1 sq. mm. cross-section.

Metal.	a	β	γ
Platinum	0·039369	0·00216407	—0 24127
Copper...	0·026577	0·0031443	—0·29751
Iron	0·072545	0·0038133	—1·23971
Aluminium	0·0595144	0·00284603	—0·76492
Silver	0·0060907	0·0005538	—0·07456

When from this formula we have calculated the increase of resistance of the coil for every rise in its temperature by a fixed amount, it is easy to state an equation, taking Ohm's law into consideration, by which a maximum can be found for I. We can also determine the ideal efficiency, as well as make the calculation by which the rate of rotation of the armature can be so modified that the largest possible amount of evolution of energy may be obtained in the external circuit.

We have now considered the effect of the number of turns of wire in the armature and its rate of rotation; there still remains the third factor, namely, the intensity of the magnetic field.

The question to be answered would, therefore, be:

V. What is the relation of the electromotive force of a generator to the intensity of the magnetic-field when the

armature has a given number of wire windings and rotates at a constant rate?

The answer is: Under these circumstances the electromotive force is proportional to the intensity of the magnetic-field; and the most important questions with reference to magneto-electric generators are thus satisfied, for the intensity of the magnetic-field is constant in these generators, and only depends on the position of the armature relative to the magnetic-poles and the judicious construction of the inducing steel-magnets or electro-magnets. But we have not yet found the answer with regard to the effect of the speed of the armature in a dynamo-electric generator; for in these generators the intensity of the magnetic-field is not constant, but directly depends on the rate of rotation of the armature, whilst the processes in the interior of the generator are rather more complicated. As regards a dynamo, therefore, we shall still have to answer three important questions.

VI. What is the ratio between current and rate of rotation in dynamo-electric generators?

VII. What relation has the effective magnetism in dynamo-electric generators to the rate of rotation of the armature, and to the increase of current?

VIII. How many turns of wire must be wound on the field-magnets, and on the armature, in dynamo-electric generators, in order to obtain the maximum efficiency?

The answers to questions VI and VII are given in an extremely interesting article by Dr. O. Fröhlich, in the "Monatshefte" of the Berlin Academy of Science, published 30th November, 1880. This article explains a theory based on a large number of experiments, and is of great value. We shall now discuss the most important points of this theory.

According to Ohm's law,

$$I = \frac{E}{R}$$

in which equation, as previously, I represents the quantity of current, E the electromotive force, R the resistance.

The electromotive force, however, as already mentioned, is proportionate to the number of windings (n) on the armature, and its rate of rotation (v), and to the intensity of the magnetic field; or, as Dr. Fröhlich expresses it, to the "effective magnetism (M)." Ohm's law can, therefore, be written thus:

$$I = \frac{n\,M\,v}{R}. \qquad (1)$$

In magneto-electric generators, with steel magnets, the effective magnetism is constant, and depends only on the strength of the magnets. In magneto-electric generators with electro-magnets, it depends on the current traversing the coils of the magnet. In dynamos this is also the case; but then we have, in addition, that it is a function of the same current, I, which it generates in the coils of the armature.

This can be written as

$$M = f\,(I).$$

Dividing equation (1) by M, we get

$$\frac{I}{M} = \frac{n\,v}{R}, \text{ or}$$

$$\frac{I}{f\,(I)} = n\,\frac{v}{R}.$$

Now, as $\frac{I}{f\,(I)}$ is a function of I, $n\,\frac{v}{R}$ depends only on I, and inversely I depends on $n\,\frac{v}{R}$.

This can be expressed as follows:

$$I = F\left(n \frac{v}{R}\right) \tag{2}$$

Or the current depends on the relation of the rate of rotation of the armature to the resistance.

This is the fundamental equation for dynamo-electric generators; and once the relation $\frac{v}{R}$ is known for a generator, all practical questions with reference to this generator can be answered.

To determine the ratio $\frac{v}{R}$ we proceed, as Dr. Fröhlich has done for Siemens' generators, to work the generator under investigation at as many different rates as possible, inserting the most varied resistances, and measuring the respective quantities of current. We then determine the ratios $\frac{v}{R}$ for each experiment, and represent them all graphically (making $n \frac{v}{R}$ the abscissa, and the quantity of current the ordinate). This gives us a curve, which Dr. Fröhlich calls the "current" curve, from which the desired data can easily be deduced.

We shall presently refer to a curve somewhat differently constructed, called the "characteristic" curve of a machine, the means M. Marcel Duprez has adopted to elucidate the internal processes of dynamo-electric generators.

If v and R are known, and we wish to find I, we look for the abscissa $n \frac{v}{R}$ in the curve, and in the corresponding ordinate we obtain the value for I; if I is known, we look for the corresponding ordinate, and get

the value for $n \frac{v}{R}$ from the abscissa; if, besides this, we know the value for v, which is always the case in practice, we can deduce the value for R from v and $n \frac{v}{R}$; if R is given, we obtain the value for v from R and $n \frac{v}{R}$.

Immediately I, v, and R are known, it is easy to deduce the values for E and M from Ohm's law.

In practice, however, the labour of determining the current curve experimentally for each generator would involve much loss of time. But this is not necessary, as Dr. Fröhlich points out, for in practice we neither employ very weak nor extremely strong currents; and for currents of medium strength the curve may be regarded as a straight line. In the fact that, within the limits occurring in practice, the current curve is a straight line, is expressed the statement that in this case I (the quantity of current) may be regarded as a linear function of $n \frac{v}{R}$. (The direction of the straight line corresponding to the curve is, of course, found by determining the end points experimentally.)

If the quantity of current is a linear function of $n \frac{v}{R}$, we can lay down the equation:

$$I = \frac{1}{b}\left(n \frac{v}{R} - a\right) \qquad (3)$$

In this equation a and b are constants; a denotes the "dead revolutions" of the armature; that is, those revolutions the generator makes during the "start," and during which no effective current is generated;

and when a is known, b is obtained from the equation—

$$b = \frac{n \frac{v}{R} - a}{I}$$

after the values for I and $n \frac{v}{R}$ have been determined for some one point in the straight line representing the curve.

If we wish to determine how far the "effective magnetism" depends on the quantity of current, we obtain from equation (3),

$$M = \frac{1}{n} I \frac{R}{v} \quad \text{(compare equation 1),}$$

and by eliminating $\frac{v}{R}$

$$M = \frac{I}{a + b\,I}. \tag{4}$$

From this equation we find that $\frac{1}{a}$ is the relation of the effective magnetism to the current when the latter is very weak, and that $\frac{1}{b}$ is the relation when the current is very strong. (This, it is true, is not quite correct, for we have arrived at this statement on the supposition that I is a linear function of $n \frac{v}{R}$, which is only true for currents of medium strength. Nevertheless, these statements tend, in general, to give a correct view of the processes.)

The dependence of the electromotive force can also be deduced from the curve by the equation

$$E = \frac{1}{b}\left(n\,v - a\,R\right)$$

With regard to the effective magnetism, in the cases

occurring in practice, Dr. Fröhlich has shown that it is incorrect to suppose that in dynamo-electric generators its increase is proportional to the current in the armature. At first, certainly, this is the case; but as the rate of rotation and the quantity of current go on increasing, the increase of the effective magnetism begins to differ more and more from the rate of rotation, and the effective magnetism finally reaches a maximum. For still larger currents, its strength actually falls off from this maximum.

The reason of this phenomenon is that the magnetism of the field-magnets not only depends on the magnetising effect of the wire-windings on their limbs (this, it is true, is the principal source), by which both these limbs and the armature (by induction) are magnetised, but also that the windings of the armature have a considerable magnetising effect on the iron of the field-magnets; which, however, counteracts that due to the coiling on the limbs, by rotating the magnetic axis of the armature, and by weakening the magnetism, especially that of the armature. Dr. Fröhlich's experiments with the Siemens generators showed that the effective magnetism of the generator is diminished by one-fourth in consequence of the magnetising influence of the coiling of the armature, more than it would be without this opposing influence. The armature acts more and more detrimentally on the field-magnets when the rate of rotation is increased beyond a certain limit. For when the limbs of the electro-magnets have been magnetised to a maximum, the influence of the current on the magnetism of the armature must still go on increasing, and the total effective magnetism therefore must decrease. This is, however, only the case with currents which far exceed in strength any employed in prac-

tice. As a rule, therefore, we may assume that the effective magnetism finally reaches a constant maximum.

With regard to question VIII., as to the most advantageous ratio between the turns of wire in the armature and those of the field-magnets, the well-known physicist Sir William Thomson put forward a hypothesis before the Paris Academy of Science on the 19th September, 1881 :—

In the field-magnets, let

L be the length of the wire ;

B the volume of the wire and insulating material ;

n the ratio of this total volume to that of the copper alone (that is, $\frac{1}{n}B$ = volume of copper) ;

A the total cross-section of the wire ; and

R the resistance of the wire.

The same values for the armature may be respectively denoted by L', B', n', A', R'. Furthermore, let s be the specific resistance of copper.

Then,

$$B = A\,L$$

$$R = ns\frac{L}{A} = ns\frac{B}{A^2}.$$

Therefore
$$A = \frac{\sqrt{ns\,B}}{\sqrt{R}} = \frac{K}{\sqrt{R}} \tag{1}$$

and
$$A' = \frac{\sqrt{n'\,s'\,B'}}{\sqrt{R'}} = \frac{K'}{\sqrt{R}}. \tag{2}$$

In these equations K and K' denote constants.

Now, let c be the quantity of current in the field-magnet, c', the current generated in the armature, v the velocity of some point on the armature, and p the mean

electromotive force at both ends of the armature-wire; then we have the equation—

$$p = I \frac{c}{A} \times \frac{1}{A'} v \qquad (3)$$

Here I denotes a co-efficient, which depends on the form, dimensions, and relative positions of B and B', and, besides on the magnetic capacity of iron. I decreases with this capacity, when the current increases, and also when R and R' undergo variations, which increase the intensity of the magnetisation.

In dynamo-electric generators with a simple circuit $c' = c$. This is, however, not the case with shunt-wound dynamo-electric generators. In both cases, however, the mechanical equivalent of the electrical work done is equal to $p\, c'$, or, according to equation (3);

$$I \frac{c\, c'}{A\, A'} v \qquad (4)$$

and putting the values found for A and A', in this equation, we get—

$$\frac{I\, c\, c'\, v \sqrt{R\, R'}}{K K'}. \qquad (5)$$

Part of this work is wasted in the heating of the wires in the coils; the other part is made use of in the external circuit. Their respective values are:

$$R\, c^2 + R'\, c'^2 \qquad (6)$$

for the work lost, and

$$\frac{I \sqrt{R\, R'}\, c\, c'\, v}{K K'} - (R\, c^2 + R'\, c'^2) \qquad (7)$$

for the useful work.

If v is very large, we can make the ratio of (6) to (7), that is, of the loss of work to the useful work, as small as we like.

The problem we now have to solve is, what relative values must be given to R and R', in order, with any given velocity, to reduce to a minimum the ratio of the wasted work to the useful work; or, in other words, if this ratio is given, to reduce the velocity to a minimum. In order to solve this question, we will call r the ratio of the total work to the loss of work.

According to (5) and (6), we then have the relation—

$$r = \frac{I \sqrt{R R'}\, c\, c'}{R\, c^2 + R'\, c'^2} \times \frac{v}{K K'}. \tag{8}$$

In the simple dynamo-electric generator, we have $c' = c$, and for (8) we obtain the equation—

$$r = \frac{I \sqrt{R R'}}{R + R'} \times \frac{v}{K K'} \tag{9}$$

or,

$$r = \frac{I \sqrt{R\,(S - R)}}{S K K'} \tag{10}$$

if we put

$$S = R + R'. \tag{11}$$

Now, let us assume that S is given, and that I is constant for a moment. Then, in order that r may become a maximum for a given v, or v a minimum for a given r, $R\,(S - R)$ must become a maximum.

This takes place as soon as $R = \frac{1}{2} S$, that is, when the resistance of the armature is equal to the resistance of the magnet. I, however, as a fact, is not constant, but decreases as the magnetising force increases. In general, I depends principally on the soft iron of the field electro-magnet, but comparatively little on the iron of the armature.

In most cases, therefore, I will decrease as R increases, and R' diminishes; consequently, the maximum for $\frac{r}{v}$

according to equation 10, requires R' should be greater than $\frac{1}{2}S$. We cannot deduce the ratio of R' to $\frac{1}{2}R'$ from the formula, without knowing the law of the variations of I. By experiments, as well as by practical predisposition, constructors were led to make the resistance of the field electro-magnets in most dynamos rather lower than the resistance of the armature, and this agrees with theory as developed.

As the useful work of a generator manifests itself as light, mechanical work, heat, or electrolytic work, we can simplify consideration in all these possible cases by substituting the typical case, where the terminals of the generator are connected by a conductor of resistance, E. Following the general custom, we call this conductor the external circuit, an expression which briefly denotes that portion of the whole circuit situated outside the dynamo-electric generator. If we have a dynamo with a simple circuit, the current traversing the external circuit is equal to that (c') traversing the armature.

According to Ohm's law, we then get the equation:

$$c' = \frac{p}{E + R + R'} \tag{12}$$

but according to equations (3), (1) and (2)

$$c' = c \frac{I \sqrt{R R'} v}{K K' (E + R + R')}. \tag{13}$$

Now, if we put $\qquad c' = c, \qquad (14)$

we get

$$I = \frac{K K' (E + R + R')}{\sqrt{R R'} v}. \tag{15}$$

The case where $c' = 0$ is the one in which

$$v < \frac{K K' (E + R + R')}{I_o \sqrt{R R'}} \tag{16}$$

where I_0 denotes that value of I, for which $c' = 0$. In order to understand this, we must remember that we do not assume any residual magnetism. For all velocities corresponding to equation (16), no current is generated. As soon, however, as this limit is passed, the electrical equilibrium of the circuit becomes stable. The slightest current then started in one or the other direction by any cause, will rapidly increase to a limiting value, determined by equation (15), in consequence of the diminution of T, which diminution coincides with the increase of the current. If we consider I to be a function of c, we have in equation (15) a mathematical expression for the current generated from the dynamo in its stationary condition. Putting equation (15) into equation (9), we get

$$r = \frac{E + S}{S} \tag{17}$$

an equation given by Joule forty years ago.

In a shunt-wound dynamo, the current c', generated in the armature, divides into two, c in the electro field-magnet and $(c' - c)$ in the external circuit. The quantities of current are inversely proportional to the resistances they traverse. Accordingly, always calling the resistance of the external circuit E, we have the equation

$$c\,R = (c' - c)\,E,$$

from which follows:

$$c = \frac{E}{R + E}\,c'. \tag{18}$$

Therefore, according to Joule's law, the work done in unit time in the three parts of the circuit is

$$\left.\begin{array}{l} R\,c'^2 \text{ for the armature.} \\ R\left(\dfrac{E}{R + E}\right) c'^2 \text{ for the field-magnet.} \\ E\left(\dfrac{R}{R + E}\right)^2 c'^2 \text{ for the external circuit.} \end{array}\right\} \tag{19}$$

From this it follows that if r represent the ratio of the total work to the useful work,

$$r = \frac{R' + R\left(\frac{E}{R+E}\right)^2 + E\left(\frac{R'}{R+E}\right)^2}{E\left(\frac{R}{R+E}\right)^2} \tag{20}$$

and, again, from this it follows that

$$R^2 r = R' \frac{(R+E)^2}{E} + R(R+E)$$

$$R^2 r = \frac{R' R^2}{E} + (R + R')E + R(2R' + R). \tag{21}$$

Now, let us assume that R and R' are given, and that E is required. In order that r may become a minimum, it must happen that

$$E = \sqrt{\frac{R' R^2}{R + R'}} \tag{22}$$

We, therefore, have

$$r = 2\sqrt{\frac{R'(R+R')}{R^2}} + \frac{2R' + R}{R}. \tag{23}$$

If we put

$$\frac{R'}{R} = e \tag{24}$$

equations (22) and (23) become

$$E = \sqrt{\frac{R R'}{1+e}} \tag{25}$$

and

$$r = 1 + 2\sqrt{e(1+e)} + 2e. \tag{26}$$

For the sake of efficiency, r must approach unity as closely as possible, and consequently e must be very small. The value for the shunt circuit approximately equals

$$\left.\begin{aligned} E &= \sqrt{R R'} \\ r &= 1 + 2\sqrt{e} \end{aligned}\right\} \tag{27}$$

Now, if we assume, for example, that the resistance of the field-magnet is 400 times as great as that of the armature, or that $e = 400$, we have approximately

$$E = 20\, R' \text{ and } r = 1 + \frac{1}{10}.$$

Or the resistance of the external circuit is twenty times as great as that of the armature, and the useful work in the external circuit is about equal to $\frac{10}{11}$ of the work wasted in the generator by the heating of the wires.

We have now become acquainted with the more important laws bearing on the construction of magneto-electric and dynamo-electric generators, and there is no doubt that it is only possible to construct a good and efficient generator when these laws are fully considered.

Nevertheless the constructor has also to take into account a large number of particulars of great importance in building an electric generator, and relating to its several parts. The most important of these are given in the next chapter.

CHAPTER VII.

THE CONSTRUCTION OF THE SEVERAL PARTS OF ELECTRIC GENERATORS.

THE most important parts of an electric generator are the field-magnets and the armature. It is on their construction and advantageous relative arrangement that the value of an electric machine principally depends.

1. **The field-magnets.**—The principal theoretical laws bearing on the general construction of magnets are given in the Appendix, and it will only here be necessary to give a few practical hints on the manufacture of magnets.

We shall take first the manufacture of steel-magnets. Steel bars can be magnetised by stroking them with steel-magnets, or by the electrical method.

In the first of these cases, we distinguish between two methods; namely, the simple stroke or the double and separate stroke.

In the simple stroke, we lay the piece to be magnetised, with one of its broader surfaces, on the opposite poles of two steel magnets, and, with the corresponding pole of a third magnet, we stroke the bar, in one way, in the direction of its longer axis. We then turn it round, so that the lower side comes atop, and repeat the operation.

In the case of the double-stroke method, we place the opposite poles of two steel magnets on the middle of the bar, and stroke with both magnets, away from the middle towards the ends.

If we wish to magnetise the bar by the electrical method, we place it inside a wire helix, which is traversed by a current. A south pole will then be generated in the piece of steel at that end of the helix at which—when it is turned towards the observer—the current circles in the direction of the hands of a clock; at the other end, a north pole will be formed.

The strength of a magnet principally depends on its dimensions, its shape, and the quality of the steel. Coulomb determined that the magnetic moment of geometrically similar magnets, composed of the same material, is nearly proportional to the cube of their homologous dimensions, and that, in cylindrical magnets of the same length, the free magnetism is proportional to the diameter.

According to the first statement, the magnetic moment of a magnet would be proportional to its volume.

Häker arrived experimentally at the result that, for horse-shoe magnets, $Q = 10{\cdot}33\ P^{\frac{2}{3}}$, in which equation Q denotes the portative power of the magnet, and P its weight in kilogrammes.

According to this equation, therefore, a magnet of 1,102 kgs. would be able to carry its own weight; and the smaller a magnet, the greater would be its portative power compared with its weight.

The co-efficient 10·33, however, is perhaps a little too small. Elias determined the value of this co-efficient to be 13·23.

But the practical value of this co-efficient is not very great, for the magnets obtained in commerce rarely attain the efficiency given by the above formula; yet, on the other hand, by special care in their construction, and by

selecting good steel, it is possible to make magnets of double this strength.

Jamin has made a series of very important experiments, with the object of ascertaining the distribution of the free magnetism in prismatic and cylindrical magnets, as well as in magnetic batteries, and also of determining the conditions for their greatest efficiency. These investigations are too extensive to be given here, even in abstract; they are, however, of great practical importance, as illustrated by the construction of the laminated magnet (described page 53), which is a result of the investigations.*

According to Frankenheim, the length of time during which the magnetising current acts on steel magnets does not influence the so-called "permanent moment" (the magnetism of steel magnets is not permanent in the true sense of the word), but this can be increased by repeating the magnetisation several times.

This can be done either by taking the piece of steel out of the magnetising helix and replacing it several times, or by opening and closing the magnetising circuit several times. By this operation the magnetic moment is increased, but, of course, only up to a certain limit.

When Frankenheim applied this method to pieces of steel which had been freshly annealed, he found that the permanent magnetism that the steel acquires after being magnetised x times, bears a certain relation to the magnetism that can be obtained with the magnetic field in question. This relation is perfectly independent of the intensity of the field, as well as of the dimensions and the coercive force of the bars. Fromme asserts that

* Comptes Rendus de l'Académie des Sciences de Paris, Vol. LXXV. to LXXVII., and Journal de Physique, Vol. V., 1876.

he obtained these results with bars which had not been annealed.

A method for making very powerful steel magnets is the following, as given by Elias.

A copper wire 7–8 m. long, and about 3 mm. diameter, is wound into a cylindrical helix, and the current of a large Bunsen's or Grove's cell, whose internal resistance is equal to that of the helix, is allowed to traverse it. The steel bar to be magnetised is placed within the helix, and the latter is then moved several times backwards and forwards from end to end of the bar. With horseshoe magnets, two helices are used, with which both limbs are magnetised simultaneously.

The distribution of the magnetism on the surface of the core is found from the equation given by Biot and Coulomb, the accuracy of which Jamin confirmed in the experiments previously mentioned. The equation is

$$y = A\left(\frac{1}{k^x} - \frac{1}{k^{l-x}}\right)$$

and it expresses the mean magnetic density at the circumference of a cross section, at distance x from one of the ends of the magnet, whose length is l.

According to Jamin, the co-efficient A principally depends on the chemical composition of the magnet; k, on the other hand, depends on its molecular constitution and on the hardness (particularly in the case of steel). When l is very large, the equation assumes the simpler form—

$$y = \frac{A}{k^x}, \text{ since } k \text{ is always} > 1.$$

In practice, the importance of the distribution of the magnetism is usually under-estimated, because, in

most generators with steel magnets, the inductive power of the poles only is employed. Marcel Deprez, however, has proved, in his small electro-motor, that this is erroneous; for with this motor very powerful effects are obtained, the inventor having placed a Siemens cylinder armature between the branches of a horseshoe magnet, with its axis parallel to these branches. The rotating armature is thus influenced by the longest portions of the limbs.

We give here the dimensions of one of the small motors, as well as the values of its working power.

The length of the horseshoe magnet, measured from the faces of the poles to the top of the bend	145 mm.
The distance between the limbs . .	33 „
The thickness of the magnetic battery .	25 „
Diameter of the cylinder armature . .	32 „
Length of the iron core	60 „
Weight of the field-magnet . . .	1·70 kg.
Weight of the whole motor . . .	2·83 „

With a motor having these dimensions, Deprez obtains, using the apparatus as a generator, all the effects that can be produced with three Bunsen's elements. On the other hand, if it is used as an electro-magnetic motor, the work produced is as follows:—

With 1 Bunsen's cell . . .	0·04 kg. metres.
2 „ cells . . .	0·20 „
3 „ „ . .	0·45 „
4 „ „ . .	0·75 „
5 „ „ . .	1·10 „
8 „ „ . .	1·80 „

In making electro-magnets, the construction of which

is important both for the inducing portion and for the armature of electric generators, it is necessary to take carefully into account the formulæ given in the previous chapter, as well as to select good material.

Unfortunately, the value of the co-efficient k, with which the intensity of the field and the volume of the magnetic core have to be multiplied, to obtain the magnetic moment, is not known with certainty for all kinds of iron; from the investigations of Barlow and Plückher, however, we know the following values, taken from Fleeming Jenkin's work.*

Soft wrought iron	$k = 32·8$
Cast iron	$k = 23·0$
Soft steel	$k = 21·6$
Hardened steel	$k = 17·4$
Soft cast steel	$k = 23·3$
Hard „ „	$k = 16·1$
Nickel	$k = 15·3$
Cobalt	$k = 32·8$

If we wish to construct an electro-magnet, it is best to use another electro-magnet as a pattern, and to make the dimensions proportional. Then, according to Dub's laws, the quantity of current required to saturate the core of the new magnet is proportional to that of the pattern electro-magnet, in the ratio of the cubes of the homologous dimensions of the two cores.

The dimensions of the coil are calculated by the laws given in Chapters VI. and X., taking into account the external resistance.

Professor Silvanus P. Thompson, in his "Cantor Lec-

* Electricity and Magnetism, p. 124.

tures" points out that to magnetise a piece of iron requires the expenditure of energy; but when once it is magnetised, it requires no further expenditure to keep it magnetised, provided the magnet is doing no work. Even if it be doing no work, if the current flowing round it be not steady, there will be loss. If it do work, say, in attracting a piece of iron to it, then there is an immediate and corresponding call upon the strength of the current in the coils, to provide the needful energy. This point Professor Thompson illustrates by the following experiment:—Let a current from a steady source pass through an incandescent lamp, and also through an electro-magnet, whose cores it magnetises. If now the magnet is allowed to do work in attracting an iron bar toward itself, the light of the lamp is seen momentarily to fade. When the iron bar is snatched away, the light exhibits a momentary increase; in each case resuming its original intensity when the motion ceases. Now, in a dynamo where, in many cases, there are revolving parts containing iron, it is of importance that the approach or a retrocession of the iron parts should not produce such reactions as these in the magnetism of the magnet. Large, slow-acting field-magnets are, therefore, advisible. And the body of the field-magnets should be solid. Even in the iron itself currents are induced, and circulate round and round whenever the strength of the magnetism is altered. These self-induced currents tend to retard all changes in the degree of magnetisation. They are stronger in proportion to the square of the diameter of the magnet, if cylindrical, or to its area of cross-section. A thick magnet, will, therefore, be a slow acting one, and will steady the current induced in its field.

It is important to have a sufficient mass, in the

magnets that saturation may not be too soon attained. The softest possible iron should be used, and this can only be obtained by very careful annealing. The magnets should be made as short as possible for two reasons. First, a long magnet means a heavy machine with a small output for its weight. Secondly, if the magnets are long the lines of force have a longer distance to travel in completing their circuits, and, experiencing a greater resistance, a greater field excitement is required for their creation. To make the path of the force lines as short as possible it is customary to utilise for the winding of the field coils as great a length of the magnets as the construction of the machine will permit. The shortness of the magnets is limited only by the requirements of the coils as regards surface for the radiation of their heat.

Pole-Pieces.—In modern machines the pole-pieces have been done away with or greatly modified in shape, a result following upon more correct notions regarding their functions. No good machines will be found now-a-days with pole-pieces as in Figs. 31 and 32. The former carried into the interior of the armature resulted from erroneous ideas concerning the theory of generators. It is true that by bringing a pole-piece inside the armature the interior wire is made active, but while the length of active wire is increased, it must be remembered that its activity per unit of length is correspondingly reduced if the total lines of force entering the armature remain as before.

If pole-pieces are required they should be of shapes really adapted to their functions. The distribution of the e.m.f. in the armature coils depends very greatly on the shape of the pole-pieces.

If the bed-plates of dynamos are of cast iron, care

should be taken that these bed-plates do not short-circuit the magnetic lines of force from pole to pole of the field-magnets. Masses of brass, zinc, or other non-magnetic metal may be interposed; but are at best a poor resource. In a well-designed dynamo, there should be no need of such devices.

The Armature.—In connection with this portion of an electric generator, another important point regarding electro-magnets has to be considered, that is, the periods of change in the magnetisation of an iron core. A magnet does not acquire its magnetism instantaneously, nor lose it instantaneously. When the circuit is closed or the current is started, the magnetic moment of the core increases rather rapidly, and reaches a maximum; again on opening the circuit or stopping the current, the magnetic moment decreases and reaches a limit more or less nearly zero. The magnetism never entirely disappears, but a small amount of "residual" magnetism remains. The duration of the increase and decrease of the magnetism depends on various circumstances; the principle is, that the coercive force of iron is never equal to zero. The separate molecules of the metal possess a certain inertia that prevents their instantly resuming the position they had before the iron was magnetised. Another reason is the occurrence of extra currents produced by induction. These have the same direction as the principal current, when the circuit is opened or the current disappears, consequently, they tend to prolong the primary current, as well as its magnetising action.

From this fact it follows that the magnetic maximum of the iron core in the armature of an electric generator does not begin to decrease when, according to theory, it should do so, but at another point. If, for instance, we

take Fig. 8 for the basis of our consideration, and assume that the ring moves in a direction opposite to that of the hands of a clock, then the maximum magnetisation of the iron core, and therefrom the maximum current, does not decrease immediately after the turns of wire have passed the poles *S* and *N*; but the magnetism of the iron core, and the current in these turns of the wire, remain at the same intensity for a few moments, so that the decrease commences a few degrees to the left of *S* and to the right of *N*. The neutral points also are displaced in consequence, and have to be sought below p and above p', and not at p and p'. This makes it necessary to change the position of the brushes, and not place them at the ends of the horizontal line joining the points p and p', but at those points which are really neutral. Affairs are made still more complicated by the fact that the amount of displacement of the neutral points depends on the greater or less rate of rotation of the armature. For when the armature rotates rapidly from right to left, each of the respective points of the ring has advanced some distance before the decrease of the magnetism of the iron core, and of the current induced in the wire windings, has reached the minimum; on the other hand, when the armature moves slowly, the theoretical and actual neutral points of the armature lie closer together. The difference in the position of the neutral points is further increased when the rate of rotation is rapid, because the magnetism of the field-magnets, and of the iron core of the armature, and consequently also the reaction on the armature coils, is increased, whereas when the rotation is slow these factors are of small value. It is therefore obvious that we should seek an automatic arrangement of the brushes to place them always on the points which are for the time

being neutral. This is already partially effected by some regulators.

Another consequence of the fact that the maximum magnetism does not immediately disappear, is the heating of the iron core of the armature, which greatly influences the efficiency of an electric generator. In any case it is necessary to prevent the peripheral current in the mass of iron of the core. This is effected to some extent by slitting the iron cores, that is, in other words, by structurally dividing the core in planes normal to the circuits round which currents are induced, which statement may be generally accepted as meaning, in planes at right angles to the direction of the wire windings, or in planes parallel to the lines of force to the direotion of the motion. Cores are also built up of varnished or insulated iron wire, or of thin sheet iron separated by varnish, asbestos-paper, or mica, to realise the required condition.

The heating of the armature, however, may not be a consequence of the residual magnetism in the iron core, but may arise from the resistance of the armature being too great. Also a part of the armature-coils are not exposed to the action of the field-magnets, and oppose a great resistance to the current which has to traverse these coils. To overcome the resistance, work is necessary, which manifests itself as heat.

One of the principal problems for the constructor is, where possible, to expose all parts of the coils of the armature simultaneously to the influence of the field-magnets, or where this cannot be done to temporarily exclude those parts of the armature from the circuit which are not accessible to the influence of the field-magnets, or are in the neutral positions, as is attained for instance in Brush's generator.

The hollowing of the armature core and the conducting of water through it, is a very incomplete remedy against heating. The injurious consequences can thus, it is true, be modified, but the work lost in the heating is not regained. Similarly the perforation of the armature for the sake of cooling by ventilation cannot be recommended, as the surface of the armature is thus increased, and the work which has to be spent in overcoming the atmospheric resistance, is lost as far as the efficiency of the generator is concerned. The rational remedy for this evil of the heating of electric generators is not to be found in modifying the consequences of the heating, but in avoiding the causes.

The position of the armature with respect to the magnetic poles must be such that the armature moves in as strong a magnetic field as possible, and this will be the case when it revolves as close as possible to the magnetic poles; for the intensity of a magnetic field is equal to the magnetising force of the pole divided by the square of the distance from the pole.

In order that the armature may rotate as close as possible to the pole, the parts of its surfaces which are turned towards the pole must be comparatively even, and we must therefore wind the coiling of the armature very symmetrically, or bring its core very close to the pole-pieces of the field-magnets by a suitable construction, as in Paccinotti's generator.

The **collectors** and **commutators** of electric generators are the parts which perhaps require most care in their construction. If they are badly constructed they wear out quickly in consequence of friction and the formation of sparks, and badly constructed collectors or commutators are the cause that a large amount

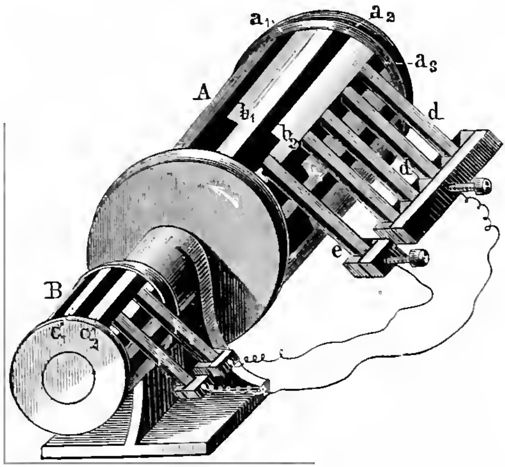
of the working power of a generator is spent uselessly.

The loss of energy through the friction of the rubbing parts of a generator is proportional to the number of revolutions of the shaft and to the diameter of the rubbing surfaces. For these reasons the surfaces ought to be diminished as much as possible, not only in the journals of the generators but also, as Professor Perry suggests, in the conducting brushes and commutators. But, besides, we must diminish the destructive action in these parts caused by sparking. This can be done by distributing the sparking over various portions of the collector, so that only small sparks can be formed, which are unable to melt or oxidize.

In order to reduce the sparking on the collectors of large generators to a minimum, Edison increases the width of the insulation a_1, a_2, a_3 (fig. 50), between the segments of the collector. He makes the conducting sectors b_1, b_2, b_3, narrower at one end of the collector-cylinder A, and on each side of this portion of the cylinder, he places a single brush e which he calls the insulated brush, the contact point of which is not in a line with the principal brushes. The insulated brush is not directly connected with the principal brushes, d d, but first with an interruption cylinder B by means of the brushes h_1, h_2. This cylinder has conducting and insulating sectors which correspond with those on which the insulated brush e bears, and it can be attached separately to one end of the shaft of the generator, or may form a continuation of the collector-cylinder A, as shewn in the figure, in which case its conducting strips c_1, c_2 must be insulated from those of the collector-cylinder A. In working the generator the local current and part of the principal cur-

rent continue to flow through each of the insulated brushes, and across each commutator segment, after having ceased traversing the principal brushes, so that no sparks are generated at the ends of the latter. When an insulated brush quits a strip of the collector, the current traversing it is interrupted on the interruption-cylinder *B*, and as the same thing occurs simultaneously on the collector-cylinder

Fig. 50.



A, through the insulated brush *e*, the spark is thus greatly subdivided and much weakened.

All the hints given in this chapter, with reference to the construction of the separate parts of electric generators, are of great importance to the manufacturer. They do not, however, by any means exhaust the details which he has to take into consideration. For the difficulties which the constructor has to overcome are of too varied a nature to be all mentioned here.

We have only been able to draw attention to the prin-

cipal points, which, if kept in view, form the basis of good construction.

The constructor has, besides, to attend to peculiarities of construction connected,

(1). With strength and simplicity of mechanical construction.

(2). With easy access to and repair of the several parts of the generator.

(3). With the cost.

A discussion of these points, however, does not come within the scope of a technological work. We shall only mention a few examples which may be regarded as typical of what has to be attended to, and of what has to be neglected under the three headings we have mentioned.

The generators of Brush and Edison, and the collector of Gramme's generator, and some of their imitations, are specially noteworthy for strength and simplicity of construction.

Brush's generator too serves as a very good type, in which the parts are very accessible and easily repaired. With regard to the latter advantage, however, we must specially mention the alternating-current generator and the latest dynamo-electric generator of Siemens and Halske, in which each bobbin can be replaced without disturbing the other parts. This is also true of the Burgin generator.

The question of cost is at present one of the principal obstacles in the way of an extensive application of electric generators, and again indirectly depends on complicated or simple construction. It is to be expected that there will be a considerable reduction in this direction as soon as the dimensions of generators are increased. For as

regards their efficiency, large generators are much cheaper than small ones, as will be seen from the details in the next chapter; and upon the whole, experience has taught that it is always advantageous to concentrate as large an amount of working-power at one point as possible, and then to distribute it in different directions. The secondary batteries described in Chapter V. promise to be of great service in this particular.

As regards the relation of size to efficiency, Professor Thompson has pointed out, in the Cantor Lectures, delivered by him before the Society of Arts, the much more than proportional efficiency of large machines. If we assume that the size of any machine can be increased n times in every dimension, and that though the dimensions are increased the velocity of rotation of the shaft remains the same, whilst the intensity of the magnetic field, per square centimetre, is also constant, the following laws of increase of size will hold good. The area the machine stands on will be increased n^2 times, and its volume and weight n^3 times.

The cost will be less than n^3, but greater than n times.

If the same increase of dimensions in the armature coils be observed (the number of layers and of turns remaining the same as before), there will be in the armature coils a length n times as great, and the area of cross section of the wire will be n^2 times as great as before; the resistance of these coils will be $\frac{1}{n}$th part of the original resistance.

If the field magnet coils are increased similarly, they will offer only $\frac{1}{n}$th the resistance of those of the original machine.

The electromotive force will be increased n^2 times, the speed of the shaft being the same.

To correspond, we may assume the whole circuit to be increased in section, so that its wire will carry the larger current, its resistance will then be $\frac{1}{n}$th of its previous value.

If our theoretical machine is "series" wound, an electromotive force, n^2, working through $\frac{1}{n}$resistance will give a current n^3 times as great as before. In this respect, as the iron of our field magnets is n^3 times as great in mass, we need not so nearly saturate it as before to gain the same magnetic field, or to get n^2 times the area of surface magnetised to the former average intensity per square centimetre. Hence, the number of coils may be reduced in the proportion of n^3 to n^2, or to $\frac{1}{n}$th of its *already diminished* value, correspondingly reducing the resistance on which work has to be done.

As in the larger machine, therefore, the electromotive force is increased n^2 times, and the current n^3 times, the work of the machine will be $n^3 \times n^2 = n^5$ times greater than with the smaller machine. Or, a machine doubled in all its linear dimensions will not cost eight times as much, and will be electrically thirty-two times more powerful than the smaller machine.

If the machine be "shunt" wound, then to produce the field of force of n^2 times as many square centimetres area, will require (if the electromotive force be n^2 times as great) that the absolute strength of the current remain the same as before in the field magnet coils. This can be effected by using wire of the same size as before, and in-

creasing its length n^2 times, to allow for n times as many turns, of n times as great a diameter each, in the same number of layers of coils as before. The current being the same, therefore, in the shunt circuit as before, but under n^2 the e.m.f., the work here is only n^2 times as great; whilst in the whole machine it is n^5 times greater than with the smaller machine.*

Following wholly different lines of reasoning, M. Marcel Deprez has arrived at the conclusion that for similar machines the "statical effort" increases as the fourth power of the linear dimensions. But as this "statical effort" is a force of mutual reaction between two elements of the system of conductors; and as work is represented by force multiplied by distance; and as, again, in the similar machine whose dimensions are increased n times, the available distance through which the new force can act is also n times greater, the value n^5 also here obtains.

* Unfortunately the reasoning here given is valueless, for if constructed on this basis the larger machine would reach a temperature destructive to the insulation. A current of n^3 through $\frac{1}{n}$ resistance would produce n^5 times the heat which with a radiating surface of n^2 would raise the temperature to n^3 times that of the smaller machine. The current is limited by the temperature to which the machine will rise and it will be found that with this limitation the output is about proportional to the weight if the number of revolutions is inversely as the linear dimensions.

CHAPTER VIII.

THE EMPLOYMENT OF ELECTRIC GENERATORS FOR PRODUCING THE ELECTRIC LIGHT.

ALTHOUGH it is not our intention to discuss fully the applications of electric generators, we think it advisable to briefly review these applications, as far as this will contribute to the understanding of the properties of the electric generators. We have also included in this chapter the more important comparative experiments relating to the efficiency of the light-generators; for, from the data as to the intensity of the light, the construction of the light-machines and the expenditure of motive power, tolerably correct conclusions can be drawn as to the individual value of the various generators.

The most important use to which electric generators have been put is undoubtedly their employment in the production of the electric light, and it was only by the invention of electric generators that electric illumination became possible on a large scale.

As has already been said, generators intended for the purpose of electric illumination must not only produce a powerful current in the external circuit, but the current must also be at considerable tension, and this again must be maintained within certain limits, for if the tension is too great the luminous arc becomes unsteady

therefore, the internal resistance of the generators must be judiciously arranged.

The internal resistance of the normal Siemens light-machine is about 0·7 or 0·75 ohms; Gramme's generators have on the average a resistance of about 1 ohm, but Gramme also constructs generators which have a resistance of only 0·6 ohm. Of course, the greater the internal resistance of a generator, the greater, generally, the e.m.f. of the current, and with generators that produce a current of low tension, we can only supply one arc-light in series; as for instance with the normal generators of Siemens and Burgin. The Brush generator, on the other hand, is capable of producing a current of such e.m.f. that 20, and even 40 lamps can be inserted in a single circuit. As regards the cost of the conductors this is a great advantage, but currents of such high intensity very considerably affect the colour as well as the steadiness of the light.

With currents of comparatively large quantity and low tension the light is steady, and in its colour resembles sunlight; for a greater part of its lighting-power is due to the incandescence of the electrodes.

It is not easy to determine accurately the comparative values of generators constructed for electric lighting; for, it is difficult to establish a fair basis of comparison. Different machines suit different conditions, and one cannot be selected to give the best results under all circumstances.

One of the most interesting communications on comparative experiments with light-machines of various construction is to be found in the report by Tyndall and Douglass, known as the "Report to the Trinity House," which embodies the result of experiments by an English

committee, in 1877, with generators for producing the light in light-houses.*

The generators employed in these experiments were—

1. A Holmes magneto-electric generator, for producing alternating currents.

2. An Alliance machine, also for generating alternating currents.

3. A Gramme generator.

4. Two Gramme generators, coupled up.

5. A large Siemens generator.

6. A small Siemens generator.

The Gramme and Siemens generators were dynamos, producing continuous or direct currents.

The Siemens generators were from the works of Siemens Brothers, in London, and the Gramme generators had been furnished by the "British Telegraph Manufactory" in London, conducted by Robert Sabine, to whom many suggestions as to the mode of measuring the light are due.

The Alliance and the Holmes machines were already in use at the South Foreland lighthouses, where the experiments were carried out.

After various preliminary experiments, the generators were tried on January 18th, with respect to the intensity of the light produced. These intensities were determined for diffused light, and for the light concentrated by reflectors. However, in the following table, we have to deduct about sixty per cent. from the intensity of illumination obtained with the dynamos, if we wish to regard

* These experiments, although at this date to be regarded as old and as made with machines the efficiency of which has been considerably increased, are yet valuable to the student as affording a comparison of the performance of earlier types now become historical with that of the later types described in the concluding Chapter.

the light-intensity as a sign of the efficiency of the generator; for the carbons in the lamps were placed more advantageously for these generators than for the alternating current generators.

The table contains the mean value of the intensity of light obtained from several experiments.

	Concentrated light.	Diffused light.
	Standard Candles.	
1. Holmes' Generator . .	1494	1494
2. " " . .	2721	2721
3. Alliance " . .	1953	1953
4. Gramme " . .	5333	3215
5. " " . .	9126	5501
6. Siemens " . .	14573	8784
7. " " . .	5920	3568

The intensity of illumination by a Gramme generator to that of the small Siemens generator (No. 58) was in the ratio of 100 to 100·6, and of the Holmes generator to the Siemens generator in the ratio of 100 to 384.

The intensity of illumination with the No. 58 Siemens generator to that with No. 68 generator was in the ratio of 100 to 109·5.

The two lighthouses on South Foreland have different heights; the light of the one was 211·7 m., and that of the other 180·6 m. distant from the engine-room. This difference in distance was accordingly employed to measure the loss of illuminating power for each generator when the current was conducted from the engine-room to the lamps, on the high and the low lighthouse. The cable employed was made up of two cables, connected with each other, each consisting of seven copper wires of No. 14 Birmingham wire-gauge, and the circuit was led

from the engine-room through both lighthouses, and back to the lamp in the engine-room.

The loss of illuminating power, due to the resistance interposed by these cables, was,

With the Holmes generator	. .	29·8 per cent.
Gramme "	. .	58·6 "
Siemens "	. .	80·4 "

On March 6th, the measurements were continued, after the collector and the brushes in the Siemens generators had been replaced by new ones; the intensity of illumination then was—

With No. 58 Siemens generator,	4,446	standard candles.
With No. 68 Siemens generator,	6,513	"
For both generators together, therefore . . .	11,009	"

When generators 58 and 68 were coupled together electrically, they gave a light of 13,179 standard candles, *i.e.*, 19·7 per cent more than the sum of the intensities of illumination with the separate generators.

The Holmes and the Alliance machine, which had both been put up in the lighthouses in 1872, had lost considerably since then in strength of current and lighting power by the weakening of the magnetism of the steel magnets—the Holmes machine about 22 per cent., and the Alliance machine about ten per cent.

Various other experiments were tried, which we cannot here describe.

The results are apparent from the adjoining Table I.

We must not, however, forget that the report of these experiments refers to generators of older construction. Since then electric generators, and especially the Gramme generators, have been much improved, as can be seen from the results which were obtained with them, accord-

TABLE I.

Name of the Generator.	Price in £.	Dimensions in m.m.			Weight in Kilogrammes.	Expenditure of work, in horse-power.	Number of Revolutions per minute.	Intensity of illumination in standard candles.		Intensity of illumination per horse-power in standard candles.		Cross section of the carbon points in m.m.	Order of ranking.
		Length.	Width.	Height.				Concentrated ray.	Diffused ray.	Concentrated ray.	Diffused ray.		
Holmes	550	1499	1321	1575	2607	3·2	400	1523	1523	476	476	9·5 × 9·5	6
Alliance	494	1321	1372	1473	1851	3·6	400	1953	1953	543	543	9·5 × 9·5	5
Gramme, No. 1	320	787	787	1245	1295	5·3	420	6663	4016	1257	758	12·7 × 12·7	4
,, ,, 2	320	787	787	1245	1295	5·7	420	6663	4016	1257	758	12·7 × 12·7	4
Siemens, large	265	1143	737	356	592	9·8	480	14818	8932	1512	911	17·5 × 17·5	3
,, small, No. 58	100	660	737	254	191	3·5	850	5539	3339	1582	954	12·7 × 12·7	2
,, ,, ,, 68	100	660	737	254	191	3·3	850	6864	4138	2080	1254	12·7 × 12·7	1
Coupled up.													
2 Holmes	1110	2997	1321	1575	5214	6·5	400	2811	2811	432	432	12·7 × 12·7	–
2 Gramme	640	1575	787	1245	2591	10·5	420	11396	6869	1085	654	17·5 × 17·5	–
2 Siemens (Nos. 58 & 68)	200	1321	737	254	381	6·6	850	14134	8520	2141	1291	17·5 × 17·5	–

TABLE II.

Generator.	Number of revolutions.	Strength of current. Ampères	Electromotive force. Volts.	Expenditure of work in horse-power.	Percentage of the electrical work obtained.	Effective work done in the arc, percentage.	Intensity of illumination in standard candles.	Price in £.	Remarks.
Two Siemens, medium size, coupled up, parallel......	680	83·9	79·55	13·4	73	39·49	19140	244	The respective light-measurements were carried out with inclined carbons.
Gramme, type D...........	500	93·78	88·72	15·1	89	47·79	27500	360	
,, ,, D...........	475	91·29	83·77	12·7	88	46·37	22500	360	
,, ,, C...........	1200	81·22	69·9	9·52	85	54·48	19500	240	
Two Gramme, type A, coupled up, parallel......	875	68·8	88·7	9·55	88	41·71	18300	160	
Wilde, Navy pattern	500	—	—	6·50	—	—	5700	450	Total light of two lamps with reflectors.

ing to the report on the experiments carried out at the School of Military Engineering at Chatham, in the winter 1879–80.

This report is important in so far as the data given were obtained from a large number of carefully-executed experiments; it is, however, impossible here to reproduce the whole.

The results of this report are given in Table II., from which we see that, calculating the mean intensity of illumination per horse-power obtained with the several generators, the Gramme generators this time gave the best results. The intensity of illumination per horse-power in standard candles is as follows:

For two Siemens generators, coupled side by side	1428
Gramme-generator, type *D*	1821
" " " *C*	2048
Two Gramme-generators, coupled side by side	1916
Wilde's generator	877

The general advantages and disadvantages of the Gramme generator *D* and of the Siemens generators are summed up in the following criticisms:

Gramme, Type *D*.

Advantages:

1. This generator gives a considerably stronger light than any of the other generators tried.

2. The generator can be entrusted to less experienced persons without fear of the wires suffering from heating or sparking.

3. During six hours continuous working, under the same conditions as with the Siemens generators coupled side by side, and with a current of 58·5 ampères, the tem-

perature of the wires only increased by 71°F. Under the same conditions the temperature of the drum of the Siemens generators was raised 110°F. and that of the electro-magnets 85°F., with a current of 55 ampères. The electro-magnets of the Gramme generator get more heated than the revolving ring, so that the maximum rise of temperature can be observed without stopping the machine.

4. Absence of sparks.—The sparking at the brushes is extremely feeble and often imperceptible; and consequently the wear of the collector and brushes is very slight. The brushes can easily be brought into the right position, and are so arranged that if necessary they can be shifted parallel to the axis of the collector.

5. Simplicity. The connections are very simple and can be easily followed.

6. With a circuit of 0·498 ohm external resistance, 47·8 per cent. of effective work was done in the arc.

7. The number of revolutions is less than in the two medium-sized Siemens generators, and less than half of the number in the Gramme *C* machine (1200); in consequence, there is less wear and tear of the generator and of the rubbing parts.

Disadvantages:

The cost of a Gramme generator, type *D*, is £360, and, accordingly, about 1½ times as great as that of the Siemens generator.

GRAMME, TYPE *C*.

Advantages:

1. The generator can be attended to by persons who have not much experience, without fear of the wires being damaged by over-heating. In this respect, this generator surpasses all the others experimented with.

2. During six hours continuous working, under the same conditions as with the two Siemens machines and the Gramme, type *D*, and with a strength of current of about 83·15 ampères, the temperature of the wire increased only 30° F.

3. Absence of sparks, see advantage 4 of Gramme *D*.

4. Compactness, see advantage 7 of Gramme *D*.

The price of this generator is £240, which is about the same as that of two Siemens medium-sized generators.

Disadvantages:

1. The intensity of illumination is only 19,500 candles, which is about as great as that of the two Siemens generators, and about 30 per cent. less than that of the Gramme *D*, when making 500 revolutions.

2. The great speed of 1,200 revolutions per minute would probably cause considerable wear of the machine and its rubbing parts.*

Two *A* Grammes, coupled side by side.

Advantages:

1. Cheapness.—The price of the two generators is only £170.

2. These generators have about the same slight amount of heating as the other Gramme machines.

3. Absence of sparks, see advantage 4 of Gramme *D*.

4. Using the generators separately, two lights can be produced.

Disadvantages:

1. The amount of light obtained with these generators is only 18,500 candles, and this is not sufficient for military purposes.

* This increased wear of the rubbing parts of properly-constructed high speed machines does not accrue in practice.—Editor.

2. When the generators are coupled side by side an inversion of the magnetism easily occurs, thus causing great disturbances and much loss of time.

Two SIEMENS machines of medium size, coupled up side by side.

Advantages:

1. By using the generators separately, two lights can be produced.

2. The intensity of illumination is considerably greater than with the other machines that were tried, excepting the Gramme generators *D* and *C*.

Disadvantages:

1. The wires are easily heated if the persons in charge are not very well acquainted with the working of this generator; it is also a disadvantage that the revolving drum is more strongly heated than the electro-magnets.

2. When the generators are coupled up side by side an inversion of the magnetism easily occurs, which causes great disturbances and much loss of time.

3. If the lamps work irregularly, there is great sparking at the brushes, causing rapid wear of the collector and the brushes.

For these reasons more experience is necessary in order to work these generators satisfactorily than with the Gramme generators.

A report of an American committee on comparative experiments with light-machines of various construction is published in the Journal of the Franklin Institute (1878, vol. 103, pp. 289–361), and the results of these experiments can be seen from Table III.

The American reporters, Profs. Thomson and Houston, remark, that if the results obtained by the American com-

TABLE III.

Name of Generator.	Total weight in pounds.	Copper conductors: Of the armature. Thickness in inches.	Copper conductors: Of the armature. Weight in pounds.	Copper conductors: Of the magnets. Thickness in inches.	Copper conductors: Of the magnets. Weight in pounds.	Number of revolutions per minute.	Foot pounds per lamp.	Horse-power.	Intensity of illumination in candles. Total.	Intensity of illumination in candles. Per horse-power.	Intensity of illumination in candles. Foot pounds per candle.	Size of the carbon points.	Length used per hour of the carbon rod. +	Length used per hour of the carbon rod. —
Large Brush generator ...	475	0·81	32	134	100	1340	107,606	3·26	1230	377	87·4	$\frac{3}{8} \times \frac{3}{8}$	1·78	0·34
Small Brush generator ..	390	0·63	24	96	80	1400	124,248	3·76	900	239	137	$\frac{3}{8} \times \frac{3}{8}$	1·91	0·58
Large Wallace generator ...	600	0·42	50	114	125	800	—	—	823	—	—	—	—	—
Small Wallace generator ...	350	0·43	$18\frac{3}{4}$	98	41	1000	128,544	3 89	440	113	272	$\frac{1}{4} \times \frac{1}{4}$	2·45	0·073
Gramme	366	0·59	$9\frac{1}{2}$	108	$57\frac{1}{2}$	800	60,992	1·84	705	338	85	$\frac{1}{4} \times \frac{1}{4}$	3·15	0·55

mittee are to be compared with the results of the English experiments of 1877, the intensity of illumination of the concentrated light, given in Table III., must be divided by 2·87, so as to equalise the difference in illuminating power caused by the different position of the carbon-points in the lamps.

In order to ascertain the ratio that the work expended in driving the generator bears to the work done in the luminous arc, the well-known French physicist Tresca, carried out experiments with Gramme's dynamo-electric generators, in the works of Sautter and Lemonnier in Paris. The experiments on October 13th, 1875, were made with a generator that could produce a light of 1850 Carcel lamps—13,690 candle power and, on September 4th of the same year, Tresca tested the efficiency of a small generator capable of supplying a light of (300 Carcel lamps) 2,220 candle power.

The following are the dimensions of the first generator:

Electro-magnets.

Diameter of the iron core of an electro-magnet	70 mm.
Length of the iron core of an electro-magnet	404 ,,
Diameter of each electro-magnet with its wire coil	132 ,,
Diameter of the wire	3·3 ,,
Weight of the wire on each electro-magnet	24 kg.

Ring.

External diameter of the core of soft iron	195 mm.
Internal diameter of the core of soft iron .	157 ,,
Width of the soft iron core . . .	119 ,,
External diameter of the ring . . .	230 ,,
Internal diameter of the ring . . .	120 ,,

Diameter of the wire coiling . . .	2·6 kg.
Weight of the wire coiling . . .	14·50 ,,

Conducting wires from the generator to the lamp:

Diameter	7·8 mm.
Cross-section	47 sq.-mm.

Generator.

Total length, including pulley . . .	800 mm.
Total height	585 ,,
Total width	550 ,,

The smaller generator was simpler in its construction, and had the following dimensions:

Electro-magnet.

Diameter of the iron core of an electro-magnet	70 mm.
Length of the iron core of an electro-magnet	355 ,,
Diameter of the electro-magnet and its wire coil	120 ,,
Diameter of the wire	3·8 ,,
Weight of the wire on each electro-magnet	14 kg.

Ring.

External diameter of the soft iron core .	168 mm.
Internal diameter of the soft iron core .	123 ,,
Width of the soft iron core . . .	101 ,,
External diameter of the ring . . .	203 ,,
Internal diameter of the ring . . .	119 ,,
Diameter of the wire	2 ,,
Weight of the wire	4·650 kg.

Conducting wires from the generator to the lamp:

Diameter	2·6 mm.
Cross-section	5·5 sq.-mm

Generator.

Total length, including pulley . . . 650 mm.
Total height . . . . 506 „
Total width . . . . 410 „

The large generator supplied a regulator lamp of Gramme's construction, the small one a Serrin lamp; both lamps had similar carbons of 8·1 sq.-mm. cross-section.

The distance of the lamps from the photometer was measured, and at the same time a diagram was taken on the dynamometer from the motor that worked the generator, and the number of revolutions recorded. From the data obtained the following table was constructed.

1. Large generator (16th October, 1875).

Ratio of the distances of the electric lamp and of the Carcel lamp from the photometer, 40: 0·93.

Ratio of the illuminating power of the electric lamp and the Carcel lamp: $40^2 : 0{\cdot}93^2 = 1850$.

Number of Trial.	Revolutions per minute of the Dynamometer.	Mean ordinates in mm., of the diagram.	Work in kilogr. metres per second.
1	238	22·50	678·28
2	251	18·89	600·56
3	248	21·74	682·82
4	244	16·60	513·00
5	241	15·59	475·86
6	244	16·65	516·23
	Mean 244		576·12 or 7·68 horse-power

$$\text{Work per 100 Carcel lamps (740 candles)} = \frac{7{\cdot}68 \times 100}{1850}$$

$= 0{\cdot}415$ horse-power.

Work per Carcel lamp (per 7·4 candles), and per second $= 0{\cdot}31$ kg.m.

2. Small generator (4th December, 1875).

Ratio of the distances from the photometer, 20 : 1·15.
Ratio of the light intensities, $20^2 : 1{\cdot}15^2 = 302{\cdot}4$.

Number of Trial.	Revolutions per minute of the Dynamometer.	Mean ordinates of the diagram in mm.	Work in kilogr. metres per second.
1	234	7·11	201·73
2	238	6·66	200·79
3	244	7·42	225·42
	Mean 239		210·65 or 2·31 horse-power

$$\text{Work per 100 Carcel lamps} = \frac{2{\cdot}81 \times 100}{302{\cdot}4} = 0{\cdot}92 \text{ horse}$$

power.

Work per Carcel lamp, and per second, = 0·69 kg.m.

The generators worked steadily, and were kept going only as long as no heating was noticed.

Comparing the results obtained with the large and the small generator, we see that in using the latter we require twice as much motive power to produce a light equal to one Carcel lamp as is necessary when we employ the large generator. These results agree with the remark made in the previous chapter, that small machines are never as advantageous as large ones.

The accuracy of this view is further confirmed by the experiments of Prof. Hagenbach, carried out at the Physico-Technical Institute, University of Basel. In these experiments were used a Gramme generator from the works of Heilmann, Ducommun and Steinlen, at Mühlhausen, a Serrin lamp, and a Bunsen photometer. For the unit of light, the paraffin candle of 21·4 mm. diameter, and 41·3 mm. length of flame was adopted.

The width of the generator, and the length of the electro-magnet was 27 c.m.; on the shaft there were

two rings, each of 48 coils. The whole of the current traversed the external circuit and was conducted round the electro-magnet.

The resistance of the luminous arc in the lamp in circuit was determined by first inserting the lamp in the circuit, ascertaining the number of revolutions of the armature, then removing the lamp and putting in as much resistance in its place, till the original number of revolutions and strength of current was again reached. The result gave 4·75 Siemens' units, for the arc, to which corresponds a total resistance of 6·63 units, during the production of the light.

The following table gives the results of the measurements for the intensity of illumination and the strength of current.

Number of Revolutions per minute.	Intensity of Illumination in Standard Candles.	Intensity of Current in cubic cm. of Gases per minute.	Electromotive Force in Deleuil Elements.
1700	506	119	40·8
1800	567	126	43·2
1900	628	133	45·6
2000	689	140	48·0

From this table it will be seen that with 1,800 revolutions, an intensity of illumination was obtained of 567 paraffin candles, which is equal to that of 80 Carcel burners; and with a Prony brake-dynamometer it was ascertained that for a speed of 1,800 revolutions per minute, 90 kg. mets. of work had to be expended per second. Consequently, in using the small generator tested by Hagenbach, 1·1 kg. mets. of work had to be expended to produce a light equal to 1 Carcel burner, and, comparing the results obtained in Tresca's and

Hagenbach's experiments, we see that the smaller the generator the more unfavourable were the results.

	Work per second for light = 1 Carcel Burner.
Generator to give light of 1850 Carcel Burners	0·3 kg.met.
" " " 302 "	0·69 "
" " " 80 "	1·1 "

In his work on electric lighting, Fontaine reports on experiments carried out in Gramme's laboratory with a generator of new construction; and from this work we take the following data and tables.

The generator employed in the experiments was a Gramme's light-machine of the normal type represented in Fig. 29, which had been constructed at the works of Mignon and Rouart.

The lamp was a Serrin regulator made by Breguet.

The carbons had a diameter of 13 mm., and were prepared by Gaudoin's process.

The motor employed to work the generator was an Otto gas-engine of 5-horse power, and which was connected with a Giroud gas-pressure regulator, introduced to prevent differences in the pressure of the gas, which might disturb the uniform working of the engine.

The Gramme generator was directly connected with the gas-engine.

The specific resistance of the cables was 0·75, silver = 1, and their cross section was 10 sq. mm.

The number of revolutions per minute of the gas-engine was 160, and the expenditure of work was not only calculated with reference to the number of explosions per minute, but in order to obtain trustworthy numbers, it was measured directly after each light-measurement.

I. Effect of the Number of Revolutions.

No. of Revolutions per minute.	Length of Cable, in metres.	Space between Carbon Points, in mm.	Intensity of Illumination, in Carcel Burners. Measured horizontally.	Intensity of Illumination, in Carcel Burners. Mean.	Work expended, in kilog. metres. Total.	Work expended, in kilog. metres. Per 100 Units of the mean Intensity of Illumination	No. of Units of Light Intensity per horse-power.
700	100	3	160	320	185	57·81	130
725	100	3	243	486	165	33·95	220
750	100	3	295	590	192	32·54	230
800	100	4	365	730	230	31·65	235
850	100	5	488	976	282	28·89	270
900	100	6	576	1152	330	28·64	260
1000	100	10	646	1292	338	26·16	285

II. Influence of the Distance between the Carbon Points.

No. of Revolutions per minute.	Length of Cable, in metres.	Space between Carbon Points, in mm.	Intensity of Illumination, in Carcel Burners. Measured horizontally.	Intensity of Illumination, in Carcel Burners. Mean.	Work expended, in kilog. metres. Total.	Work expended, in kilog. metres. Per 100 Units of the mean Intensity of Illumination	No. of Units of Light Intensity per horse-power.
750	100	5	351	702	175	25·	301
750	100	4	321	642	186	29·	259
750	100	3	295	590	192	32·5	281
750	100	2	256	512	214	41·7	214
750	100	1	225	450	233	51·6	145
750	100	0	140	280	330	117·8	63

III. Influence of the Length of the Cable.*

No. of Revolutions per minute.	Length of Cable, in metres.	Space between Carbon Points, in mm.	Intensity of Illumination, in Carcel Burners.		Work expended, in kilog. metres.		No. of Units of Light Intensity per horse-power.
			Measured horizontally.	Mean.	Total.	Per 100 Units of the mean Intensity of Illumination	
750	100	4	321	642	186	28·9	267
800	150	5	345	670	230	33·3	225
825	200	5	315	630	232	36·8	178
850	300	5	275	550	225	40·9	183
900	400	5	260	520	241	46·3	162
950	500	5	245	490	230	46·1	160
1000	750	5	236	472	243	51·4	145
1100	1000	5	215	430	256	59·5	126
1350	2000	5	160	320	230	71 8	104

IV. Influence of the Length of Time during which the Generator was Worked.

No. of Revolutions per minute.	Length of Cable, in metres.	Space between Carbon Points, in mm.	Length of Working.	Intensity of Illumination, in Carcel Burners.		Work expended, in kilog. metres.		No. of Units of Light Intensity per horse-power.
				Measured horizontally.	Mean.	Total.	Per 100 Units of the mean Intensity of Illumination	
750	100	2	Starting.	199	398	214	53·7	139
750	100	4	15 min.	180	380	183	50·8	147
760	100	4	30 „	175	350	194	55·4	135
750	100	4	1 hour.	181	362	191	53·	142
750	100	4	2 „	191	382	192	50·2	149
750	100	4	3 „	190	380	190	50·	150

* In all the experiments the cross section of the cable was 10 sq. mm.

For measuring the intensity of illumination, a Foucault photometer was employed.

The tables, pages 200 and 201, contain the results of the experiments.

The last column in Table I. shows that a light of 285 Carcel burners (1,909 standard candles) was obtained per horse-power, which is a far more favourable result than any given by other experimentalists.

Table II. shows the effect of the distance between the carbons; the length of the cable and the number of revolutions being constant. For practical purposes, however, the distances given are not all applicable, for if the distance between the points of the carbons was 5 mm., the light burnt very unsteadily, and it was only the results obtained with a distance of 3 mm. that were of practical value.

Table III. shows the influence due to the length of the conducting wires on the expenditure of work (and on the intensity of the light.)

From Table IV. it can be ascertained what is the ratio between the current when the dynamo is started, to the current when equilibrium is established.

According to Fontaine, the result shows that, using a Serrin lamp the most satisfactory results are obtained with the Gramme generator (normal Type) working at the speed of 750 revolutions, with the carbon points 3 mm. apart and the cable having a length of 100 mm.

The mean intensity of illumination (of the diffused light) is then equal to 590 Carcel burners for an expenditure of work of 192 kgr. met. (2·55-horse power), and this corresponds to 32·5 kgr. met. per 100 Carcel burners.

CHAPTER IX.

VARIOUS APPLICATIONS OF ELECTRIC GENERATORS.

NO other application of electric machines has been so successful as their employment for lighting; but in other ways these machines have proved of great value; and in various industries their introduction in place of the batteries formerly used has brought about so complete a revolution that we can predict with certainty, that these generators are not only destined to supplant almost all other methods of producing currents, but also that innumerable applications will still be found.

Electric generators for plating and electrotyping purposes, for instance, render excellent service, and, in them, we not only have apparatus that is more cleanly and convenient, supplying electrical energy more cheaply than galvanic batteries, but, what is far more important, the current remains perfectly constant and uniform. It was only by employing electric generators, that it became possible to execute the delicate and artistic pieces of galvano-plastic workmanship as are, for instance, supplied by the firm of Christofle & Co., in Paris; or, that the coating of very oxidizable metals with other metals could be effected on the present scale. Since the invention of electric generators, gilding, silvering, nickeling and tinning have become so universal that it is only in few branches of the trade that easily oxidized metals are employed without an artificial coating, and

these coatings are not only an important advance from an artistic point of view, but the durability of all articles made of common metals is greatly enhanced.

With regard to the construction of generators intended for galvano-plastic purposes, we have to remember that, unlike the light-generators, they have to produce currents of comparatively low intensity, but of large quantity. In plating and typing machines therefore, constructors have endeavoured to employ coils of very thick wire. In principle, generators with electro-magnets, which receive their current from an exciting machine, would probably be the best for galvano-plastic purposes, for with these generators there would be no fear of an inversion of the current from the polarisation of the electrodes; at present, however, dynamo-electric generators are chiefly used, modified in construction, or connected with special current interrupters, to prevent a change of polarity of the field-magnets.

In order to understand this, we must remember that if the field-magnets of the generator are inserted in the same circuit with the galvano-plastic apparatus (as is, in fact, the case if the dynamo-electric principle is alone employed), a current of opposite direction, which has been generated in the galvano-plastic bath by the polarisation of the electrodes, will traverse the coils of the electro-magnets when the generator is brought to a standstill. This current then suffices to impart a small amount of residual magnetism to the iron cores, converting the former south and north poles into north and south poles respectively. If we again set the generator in motion, this polarity will start the new current, and accordingly, a current will enter the galvano-plastic apparatus, which will have a direction opposite to that of the original

current, and which will, of course, re-dissolve the deposit, and destroy the previous work.

This evil can only be remedied by not alone employing the dynamo-electric principle in the generators, but by conducting a portion only of the current through the galvano-plastic baths, whilst the other portion is used to excite the field-magnets; or the return of the opposite current can be prevented by the use of a current interrupter, an apparatus that interrupts the connection of the conducting wires between the galvano-plastic bath and the generator, at the moment when the latter stops, or when the current generated by it can no longer keep back the opposing current. Many such current interrupters have been constructed.

The **current interrupter** employed by Gramme consists of a balanced piece of iron which has a counterweight. It connects the brushes which bear on the collector with the electro-magnets. As long as the armature of the generator rotates with a certain speed, the magnetism of the electro-magnets is strong enough to hold the piece of iron by the power of attraction. As soon, however, as the speed slackens, and the current accordingly becomes weaker, the magnetism of the electro-magnets is diminished, the piece of iron falls off, and the circuit is interrupted between the electro-magnets and the galvano-plastic apparatus which is connected with the brushes; no polarising current can, therefore, reach the magnetising coils of the machine.

Weston's circuit closer is rather more complicated. It consists of a small iron column, which carries a spindle in a horizontal collar, and on the spindle is a disk provided with two radial grooves. In each groove of this disk there is a metallic slide-block, and when the gene-

rator is not working (the disk rotates simultaneously with the armature) this block is pressed towards the centre by a spiral-spring, where it rests on a metallic nave, which is insulated from the disk. A metallic spring, connected with one of the conducting wires, bears on the nave, whilst the slide-blocks are connected with the other conducting wire. When, therefore, the generator is at a standstill, the slide-blocks and the nave are in metallic contact, and these remain so, as long as the rate of rotation is not great and the current is but weak; in this case, therefore, the latter will flow through the short circuit established by the current-closer. However, if the speed of rotation of the armature and, therefore, also of the disk increases, the two slide-blocks are driven towards the circumference by the centrifugal force, and are pulled away from the metal nave. The current must, therefore, now flow through the galvanoplastic apparatus and the coils of the electro-magnets, that is, it must traverse the larger circuit. From what we have said, it will be seen that, while Gramme prevents polarising currents entering the coils of the electro-magnets of the machines, when the speed slackens, by interrupting the circuit, Weston attains the same result by establishing a shunt-circuit which is selected by the current, on account of its smaller resistance, as soon as the metallic contacts allow it.

Möhring's current interrupter is only a modification of the Weston current closer.

In Möhring's generator, the disk of the current-closer, which has three slide-blocks, is connected with the collector. These slide-blocks bear against the rim of the disk only when the generator attains a certain speed, thus producing metallic connection between the parts of the

collector; but, when the generator revolves slower, the slide-blocks are not in contact with the rim, and the circuit is thus interrupted.

Besides the current closers and interrupters we have described, there are others that have done good service, but a description is superfluous, as the principle will be understood from what has been said, and the construction can, of course, be varied in numerous ways.

If magneto-electric generators are employed for galvano-plastic purposes, whose field-magnets are not in the same circuit as the galvano-plastic bath, no precautionary apparatus is necessary for preventing polarising currents from entering the generator.

The application of dynamos for **obtaining pure metals** on a large scale was mentioned when we were describing Siemens' generators; we also called attention to the application of electric machines to the **preparation of ozone,** and from the results obtained we may conclude that in time the employment of electric generators in the various branches of industry will attain great importance.

Another application of the electric current worth mentioning, and which only became possible through the invention of electric generators, is the **melting of very refractory metals.**

The extremely high temperature necessary to melt platinum and iridium, formerly made the working of these metals very difficult and expensive, whereas by means of the great heat which powerful electric currents can produce, it is comparatively easy now to work them, as well as to carry out those chemical reactions and decompositions which require a specially high temperature.

Sir William Siemens, of London, deserves the merit of having constructed a suitable apparatus for melting re-

fractory metals by means of the electric current. The Siemens smelting apparatus consists of a crucible made of graphite, or some other refractory material, which is placed in a metal vessel. The crucible, does not, however, touch the inside of the metallic vessel, but is separated by a layer of pounded wood, charcoal, or some other bad conductor of heat. The positive electrode, a bar of gas-carbon, projects through the bottom of the crucible into the interior, whilst the other electrode, represented by a rod of compressed carbon, passes through the cover of the crucible. Both electrodes are kept at a suitable distance from each other by an automatic regulator, of simple construction, and the electric arc thus remains uniform. When a dynamo was employed, which absorbed 4 horse-power in its working, and produced a current of 36 ampères, Siemens found that a crucible 20 c.m. in depth was rendered white hot in less than a quarter of an hour; and that in the next quarter of an hour a kilogramme of steel could be caused to melt. The subsequent meltings were carried out even more rapidly.

Electric generators are now used most successfully in **telegraphy**. The first experiments were carried out in India, in the autumn of 1879, by L. Schwendler, who conducted a portion of the powerful current of a dynamo, used in the telegraph workshops of the Alipore government for lighting, through the 850 miles of telegraphic wire between Agra and Calcutta, and with it he was able to transmit a number of telegrams without change being noticed in the brightness of the electric light, for the portion of the current conducted away was only about ·004 of the total current.

Encouraged by this favourable result, Schwendler supplied all the wires of the Calcutta telegraph office with

branch currents from a dynamo, and the result was most satisfactory. In other places, too, electric generators have proved of use in telegraphy.

L. Kohlfürst, of Prague, employed a small magneto-electric machine for the same purpose, and with it he worked three Morse printing telegraphs. Very satisfactory results too were obtained with electric generators at the Central Station of the Western Union Telegraph Company, in New York. They did not, as in Schwendler's experiments, use only one generator, from which the various currents were branched off; but a number of Siemens generators, whose electro-magnets were excited by the current from a dynamo, were coupled up, and the necessary currents were thus produced.

The result was so favourable that the Western Union Telegraph Company now solely employ electric generators for telegraphic purposes, instead of batteries. The current of these machines supplies the 360 wires issuing from the principal station, and also the cables of the Gold and Stock Telegraph Company.

The generators occupy only a tenth of the space formerly taken up by the batteries, and one engineer is able to look after the whole of them.

The company believes that through the introduction of electric machines the working expenses will be reduced 50 per cent.

We have already mentioned the employment in physical laboratories and for medical purposes of the smaller electric generators, worked by hand or foot, and with regard to these we need only add that as soon as the expense of their construction is diminished, they will quite possibly definitely replace galvanic batteries.

The most interesting application of electric machines,

and that which has the greatest future, is their **application to the transmission of power.**

As regards this application we shall in the present volume confine ourselves to a few general statements. The principle of the electrical transmission of energy is that by transmitting the motion of a steam-engine, or any other motor, to an electric generator a current is produced, and by means of conducting wires this current is then conducted to a second electric generator, where it is again converted into mechanical work. In this way the work done by a steam-engine can be transmitted to any distance. It is true that as yet we have not succeeded in effecting this transmission economically, and that, with generators as constructed at present only about 50 per cent. of the work done at one station is obtained again at the other station. When, therefore, the motive power has to be provided by an expensive method, the electric transmission of energy rarely pays.

At first, it was supposed that the transmission of an immense amount of energy, such as that of the Niagara Falls, would necessitate an inordinately thick cable. Prof. Perry, of London, however, explained in a lecture, given at the Society of Arts, on March 24, 1881, that with a suitable arrangement of the generators employed, and with sufficient insulation, the whole energy of the Niagara Falls might be transmitted to New York through a telegraph wire.

Amongst the applications which have as yet been made of the electrical transmission of energy, are the working of agricultural machines by means of stationary motors at a great distance, as for instance, in the experiments of Chrétien and Felix, at Sermaize; the electrical railways of Siemens-Halske, electrical lifts, &c. The time is not

far off when it will be possible to transmit energy from large central stations, in the form of the electric current to all the houses of a town. There the inhabitants will then be able to convert it into light, heat, or mechanical energy as they like, and to employ it for all possible purposes. There is no doubt but that in time magneto, and dynamo-electric generators are destined in many cases to replace steam motors.

CHAPTER X.

FORMULÆ FOR THE CONSTRUCTION OF ELECTRO-MAGNETS.

ALTHOUGH in this book we have assumed that the reader has a general knowledge of the theory of magnetism, and although it is outside our scope to enter fully on theoretical questions, still it appears desirable that, in a manual on electric generators, the formulæ should be given that relate to the construction of the most important parts of these generators, the electro-magnets. Accordingly, as a supplement to Chapter VII., we give some equations by which, according to Du Moncel, the best conditions for the maximum intensity of the magnetic moment, and of the attractive power, can be easily found.

Let—

a = the thickness of the magnetising coiling;
b = the total length of the two coils, or of the two limbs of the magnet;
c = the internal diameter of the coils, which practically is assumed as the diameter of the magnetic core;
g = the diameter of the wire and insulating material;
A = the attractive power of the horseshoe magnet;
E = the electromotive force of the current;
M = the magnetic moment;
H = the length of wire on the exciting coil;

I = the strength of current in the whole circuit;
t = the number of turns of wire on the limbs of the magnet;
R = the resistance of the external circuit.

In this case we can denote the number of turns of wire in each layer by $\frac{b}{g}$, and the number of layers in each coil by $\frac{a}{g}$.

The number of turns of wire will, accordingly, be obtained from the equation—

$$t = \frac{b}{g} \times \frac{a}{g} = \frac{b\,a}{g^2}. \qquad (1)$$

Further, the length of a turn, in the layer which lies directly on the core, is—

$$2\pi\,\frac{c + g}{2}\,.$$

and the length of a turn in the outermost layer is—

$$2\pi\,\frac{c + 2a - g}{2};$$

consequently the total length of the wire in each of these two layers is—

$$\frac{b}{g}\,2\pi\,\frac{c + g}{2}, \text{ and } \frac{b}{g}\,2\pi\,\frac{c + 2a - g}{2}$$

Now, as the layers between these two form an arithmetical progression, the first and last terms of which are given by the two preceding expressions, and as the number of terms is equal to $\frac{a}{g}$, we find the total length of the wire in the exciting helix from the equation—

$$H = \frac{b}{g}\,\frac{2\pi\,(c + g + c + 2a - p)}{4}\,\frac{a}{g} = \frac{\pi\,b\,a\,(a + c)}{g^2}. \quad (2)$$

The values of t and H are therefore functions of those for a, b, c and g; and having measured the thickness of the insulated wire, and the thickness and length of the coil, and having counted the number of turns in the coil, we can easily calculate the length and number of the turns wound on a magnetic core, if we divide the length of the coil by the number of turns, and determine the difference between the external and internal diameter of the coil. Similarly, we can, if necessary, find the values for a and g from the above equation, or establish other expressions for A and H.

The electro-magnetic force of the magnet is found by taking into account the laws of Jacobi, Dub, and Muller, who have determined that the actual strength of a magnet—or, according to the physical term, its magnetic moment, M—is equal to the strength of the current flowing through the magnetising helix, multiplied by the number of turns of wire, and that its power of attraction, A, is equal to the square of the magnetic moment.

From this we get the formulæ—

$$M = \frac{E\,t}{R + H} \text{ and } A = \frac{E^2\,t^2}{(R + H)^2}.$$

Now, if in these formulæ we substitute the values for t and H previously found, we obtain the equations—

$$M = \frac{E\,a\,b}{R\,g^2 + \pi\,b\,a\,(a + c)} \text{ and}$$

$$A = \frac{E^2\,a^2\,b^2}{[R\,g^2 + \pi\,b\,a\,(a + c)]^2}.$$

These equations show that we can obtain maximum values of strength for M and A in various ways, accordingly as we change the value for a, b, c or g. The prin-

cipal conditions on which these maxima depend are: 1, The resistance of the coil; 2, The ratio of its diameter to the diameter of the core; 3, The dimensions of the magnet itself.

In practice, it will always be desirable to find an expression for R, which expression will be a function of the resistance of the magnetising coil. This is arrived at in the following way.

First of all we divide g, which denotes the diameter of the wire and its insulation by a coefficient, f, in order to obtain the diameter of the bare wire, as it is that alone which comes into consideration when we calculate the resistance. (In practice, this coefficient may be taken as 1·6 for very fine wires, and as 1·4 for medium wires.) The diameter of the bare wire is therefore $\frac{g}{f}$; and if by q we denote the ratio of the efficiency of conductor R to that of conductor H (including the constants, referring to conductivity per unit of cross-section, which is 0·000016), we obtain $\frac{q\,R\,g^2}{f^2}$ as the reduced value for R.

Because, with the increase in thickness $\left(\frac{g}{f}\right)$ of the wire, not only the resistance of a coil of constant diameter, but also the length of its wire, is diminished — two values which vary at the same rate—the resistance, H, of the coil will be inversely proportional to g^4, instead of to g^2, but the quantity, $\frac{q\,R\,g^2}{f^2}$, will remain inversely proportional to g^2, so that for the nominators of M and A we get the following expressions:

$$\frac{q\,R\,g^4 + 4\,b\,a\,(a + c)\,f^2}{f^2\,g^4}; \left[\frac{q\,R\,g^4 + 4\,b\,a\,(a + c)\,f^2}{f^2\,g^4}\right]^2$$

The values for M and A themselves are:

$$\left.\begin{aligned} M &= \frac{f^2 g^2 E a b}{q R g^4 + f^2 \pi b a (a + c)} \\ A &= \frac{f^4 g^4 E^2 a^2 b^2}{[q R g^4 + f^2 \pi b a (a + c)]^2} \end{aligned}\right\} \quad (3)$$

Having thus determined the values for M and A, the question arises as to what are the conditions for obtaining maximum values for A and M. We shall first consider—

I. The dependence of the maximum values of A and M on the resistance of the magnetising coil.

This dependence would have to be ascertained if we were desirous of employing an electro-magnet of given dimensions, and wished to select such a thickness of wire as would enable us to obtain a maximum for the values A and M, when the resistance of the external circuit is given; or if, with a given external resistance, we wished to employ a particular kind of wire for the magnetising coil, and wished to calculate the dimensions of the latter, with which M and A would obtain their maximum values. In the first case, the variable is g, or the diameter of the wire; in the second case, it is the thickness of the coil.

If we now take into consideration that, in the formulæ (3), the diameter of the wire is not g, but $\frac{g}{f}$, in which expression f denotes a constant, we see that the calculation is not so simple as it would seem to be at first sight. The physicists who first occupied themselves with this question had assumed that they might neglect f entirely in the calculation, and might put g for the diameter of the wire and its insulation. Even when the value for f was taken into account—as, for instance, in the formulæ

(3)—it was supposed that this value could not be expressed by a constant when the value of g varied, and in consequence the final results obtained were different.

Considering the question from the simplest point of view, we see that the maximum values for M and A are obtained when

$$\frac{q\,R\,g^2}{f^2} = \frac{\pi\,b\,a\,(a+c)}{g^2};$$

that is, when $R = H$; or, in other words, the most advantageous diameter of the wire will be that which makes the resistance of the magnetising coil equal to that of the external resistance.

If we take the thickness of the insulating covering into consideration, the coil that will render the best service will be that of which the resistance is to the resistance of the external circuit as the diameter of the bare wire is to the diameter of the insulated wire.

Another law which can be deduced from these formulæ is:

Of different magnetising coils that have wires of the same diameter, but contain different numbers of turns, the most efficient will be that in which the resistance is to the resistance of the external circuit as the thickness of the coiling and of the iron core is to the thickness of the coil alone.

II. Dependence of the maximum strength of A and M on the ratio of the thickness of the magnetising coil to the thickness of the iron core.

As the strength of an electro-magnet increases with the dimensions of the core, and as the resistance of the exciting coil also increases proportionally to these dimensions, we must, of course, ultimately reach a maximum for the magnetic intensity; and it is important, in the con-

struction of electro-magnets, to know the law with regard to this maximum.

This law is obtained from the following equations,

$$M = \frac{g^2 E \sqrt{c}}{\lambda \pi b (a + c)} \text{ and } A = \frac{g^2 E^2 c}{[\lambda \pi b a (a + c)]^2} \quad (4)$$

where λ is a coefficient, with which the length of the wire in the coil must be multiplied in order to obtain a maximum in the circuit; and if the values of A and M are ascertained with regard to c and have been equated, it will be seen that maximum values are obtained for them, when $a = c$, that is, when the thickness of the exciting coil is equal to the diameter of the iron core.

The calculation for the maximum of A and of M is now very simple, since, under the conditions found for the maximum, the expression for the length of the wire in the magnetising coil becomes $\frac{2\pi b c^2}{g^2}$, and if we express the length b of the magnets as a function of the diameter c, by multiplying the latter by m, which experiments shew to be equal to 12, for the two branches of the magnet, we obtain the expression

$$\frac{2\pi c^3 m}{g^2} \text{ or } \frac{75{\cdot}4 \times c^3}{g^2} \quad (5)$$

in which the values of c and g occur. For the number of turns t, we then get

$$t = \frac{12 c^2}{g^4}.$$

Now, we see that A and M are maximum values when $R = H$, $a = c$, $b = cm$, and it follows that as g is not known we must find a value for R, that is a function of g, and this we get from the value of

$$H = \frac{2\pi c^3 m}{g^2}$$

which is equal to R, and we write

$$\frac{q\,R\,g^2}{f^2} = \frac{2\pi\,c^3\,m}{g^2}.$$

From this it follows that

$$g^4 = f^2\,\frac{c^3}{R}\,\frac{2\pi\,m}{q}; \tag{6}$$

and, finally, because $\frac{2\pi\,m}{q}$ is a constant, which is composed of known numbers and is 0·00020106, we get the equation

$$g = \sqrt{f\sqrt{\frac{c^3}{R} \times 0{\cdot}00020106}}. \tag{7}$$

III. The dependence of the maximum strength of M and A on the length of the iron core.

From what has been said, it appears that it is important for the calculation, that the length of the magnetic core be expressed as a function of its diameter, but it is still a question whether the iron core may be lengthened indefinitely or whether we can also determine a maximum value for this length.

Since according to Müller's law, the values of A and M are proportional to the square root of the diameter, we can find no maximum values in these cases, as long as b varies; but if we express b as a function of the diameter c, the power of attraction becomes proportional to $c\,m\,\sqrt{c}$ or to $c^{\frac{3}{2}}$; if we now take into consideration all the conditions found so far for the maximum strength, we get

$$A = \frac{E^2\,m^2\,c^4\,c^{\frac{3}{2}}}{[R\,g^2 + 2\pi\,c^3\,m]^2} \tag{8}$$

in which equation R is represented by a certain length of wire of the coil.

From this equation we then further obtain

$$\frac{2\pi\,c^3\,m}{g^2} = 11\,R.$$

In other words: we can increase the dimensions of the iron core till the resistance of the magnetising coil is eleven times as great as the resistance of the external circuit.

In that case we get

$$m = 11 \frac{R\, g^2}{2\pi\, c^3}$$

and from this we see that m is eleven times as great as the ratio of the resistance R of the external circuit, to that of the coil, for which latter in this case we have the expression $\frac{2\pi\, c^3}{g^2}$. Now, because in order to obtain the maximum intensities for A and M, the two resistances, as we have seen, ought to be equal, it follows that their ratio is equal to 1, and m in consequence $= 11$. Practically, however, we must assume m to be $= 12$, on account of the magnetic poles usually having rather larger diameters than the core, the wires, too, as a rule, not being directly wound on to the iron, and on account of similar minor causes, on which the deviations from theory depend.

From the preceding formulæ, some important consequences may be deduced:—

1. For equal circuit resistance, the diameter of the electro-magnets under maximum conditions should be proportional to the electromotive forces employed.

2. For equal electromotive forces, the diameter should be in inverse ratio of the square root of the resistance of the circuit, comprising that of the generator.

3. For equal diameters, the electromotive forces should be proportional to the square roots of the resistance of the circuits.

4. For a given electro-magnetic force, and with electro-magnets under their conditions of maximum, the electromotive force of the generators should be proportional to the square roots of the resistance of the circuits.

If it be considered that the expression $I^2\, t^2\, c^{\frac{3}{2}}$, which represents this force, may be converted by successive substitutions in the values of I, of t, and of c, into $\frac{E^{\frac{9}{2}}}{R^{\frac{9}{4}}} \times \frac{Q}{f^2}$ a formulæ in which Q is a constant equal to 2228 (if the electromotive force be taken in unity of a Daniell's element, and the resistance in metres of telegraph wire), there is attained for the same attractive force the ratios $\frac{E^{\frac{9}{2}}}{E'^{\frac{9}{2}}} = \frac{R^{\frac{9}{4}}}{R'^{\frac{9}{4}}}$ or $\frac{E}{E'} = \frac{\sqrt{R}}{\sqrt{R'}}$. As in the values E and R there come in the numbers n and n' of elements employed, these numbers may be easily calculated, knowing the values of the constants e and ρ of the elements employed, for $\frac{n\, e}{n'\, e'}, = \frac{\sqrt{n\, \rho + r}}{\sqrt{n'\, \rho' + r'}}$, and if the accentuated quantities refer to those of a known typical electro-magnet, the value of n may be easily deduced.

If, in the problem to be solved, the attractive force of the electro-magnet is expressed as a weight P, and modifying this value by a co-effcient K, which represents the ratio $\frac{F'}{P'}$ deduced from data from the typical electro-magnet, there may be taken for the value of this constant for attraction at 1 millimetre, $\frac{0{\cdot}002297}{26{\cdot}85}$, or say 0·00008555. It may be remarked that the quantity F in this ratio represents, for the typical electro-magnet, the formula $I^2\, t^2\, c^{\frac{3}{2}}$ or its equivalent; and it will result from putting $\frac{n\, e^{\frac{9}{2}}}{(n\, \rho + r)^{\frac{9}{4}}} \times \frac{Q}{f^2} = P\, K$, that

$$n\, e = \sqrt{n\, \rho + r} \times \sqrt[3]{\sqrt[3]{\frac{f\, 4\, P^2\, K^2}{Q^2}}},$$

and if the two constants Q and K be combined,

$$\frac{n^2 e^2}{n \rho + r} = \left(0{\cdot}0225 \sqrt[3]{\sqrt[3]{f^4 P^2}}\right)^2.$$

Representing by M the parenthetic quantity, which may be easily calculated,

$$n = \frac{M^2 \rho}{2 e^2} + \sqrt{\left(\frac{M^2 \rho}{2 e^2}\right)^2 + \frac{M^2 r}{e^2}}.$$

If instead of a simple circuit, there were x derivations from the same pole of the battery, and on these derivations are interposed electro-magnets of equal resistance and dimensions, the quantity of current on each derivation would be

$$\frac{i E}{x \frac{i}{h} \rho + H} \text{ or } \frac{h E}{2 x \rho},$$

where i is the number of series of h cells in parallel circuit; and the values of i, h, or n will be the same as in the more simple case, but multiplied by x.

As a numerical example of the preceding formulæ, suppose, in an electro-magnet, it be desired to have an attractive force of 273 grammes, at 1 millimetre distance from the armature, on a circuit of 50 kilometres resistance, say 500 ohms, with a bichromate of potash sand battery. In this battery the value of the electromotive force, e, of each element is 2 (that of a Daniell being 1), and the resistance, ρ, about 1,000 metres of telegraph wire, say 10 ohms. According to the formulæ—

$$A = 0{\cdot}0225 \sqrt[3]{\sqrt[3]{1{\cdot}37^4 \times 273^2}} = 0{\cdot}09;$$

and

$$A^2 = 0{\cdot}0081 \times n = \frac{8{\cdot}1}{8} + \sqrt{\left(\frac{8{\cdot}1}{8}\right)^2 + \frac{0{\cdot}0081 \times 50{,}000}{4}} = 11{\cdot}125;$$

whence

$$c = \frac{11{\cdot}125 \times 2}{\sqrt{61{,}125}} \times 0{\cdot}173 = 0{\cdot}01553 \text{ metres.}$$

This gives for the length of each bobbin 0·0932 metre; for the diameter of the wire, with its covering, 0·39 millimetre, and without, 0·28 millimetre; for length 1,861 metres; number of turns, 19,078; for quantity of current (not ampères, of course), 0·0001859; for value of $c^{\frac{3}{2}}$, 0·001935. Squaring the values of I and t, and multiplying by $c^{\frac{3}{2}}$, there is obtained 0·024378, which represents the electro-magnetic force, and this value, compared with that of the typical electro-magnet (experimented with by Du Moncel), which is 0·002297, gives the ratio 10·6, nearly that of the two weights 273 and 26·85, representing the attractive forces in grammes.

Conditions for Maximum on Shunt Circuits.—The preceding deductions suppose that the permanent state of electric propagation is established, that the reactive effect of the extra current from the electro-magnet does not occur, that the iron of the electro-magnet is magnetically saturated, and that the exterior circuit, R, is perfectly insulated. When these conditions do not exist, Hughes' experiments have shown that the resistance of the helix must be considerably reduced.

To consider the most simple case, that of a single derivation u established on a circuit of resistance l, with a common resistance R in the battery circuit, the attractive force A of the electro-magnet interposed on l will be—

$$A = \frac{E^2\, u^2\, l^2}{[R\,(u + l + H) + u\,(l + H)]^2},$$

and if, for t and H, be substituted their true values,

drawn from the equations previously given, there is obtained in relation to g, considered as variable—

$$\frac{q\,g^2}{f^2}\left(l + \frac{R\,u}{R + u}\right) = \frac{\pi\,b\,a\,(a + c)}{g^2},$$

an equation consequently corresponding to the conditions of maximum.

In varying the thickness of the helix, the quantity g remaining constant, these conditions of maximum are represented by—

$$\frac{q\,g^2}{f^2}\left(l + \frac{R\,u}{R + u}\right) = \frac{\pi\,b\,a^2}{g^2}.$$

Now, in the first of these equations, the second member represents the resistance of the wire of the helix, and the first member is the total resistance of the external circuit, expressed in units of the same order as those used in the evaluation of the length of the helix wire. But this total resistance is taken in inverse sense, because that which is under consideration is really represented by $R + \frac{l\,u}{l + u}$. In this case, the total resistance should be supposed as if the part common to the two derived currents were represented by the shunt circuit l, and as if the part really common, R, were only a simple shunt circuit.

In the second equation, the first member represents, as before, the total resistance of the circuit taken in inverse sense; but this total resistance, as the resistance R of an insulated line, should be considered as being smaller than that of the helix in the ratio of 1 to $1 + \frac{c}{a}$, to satisfy the conditions of maximum relatively to the variable a.

Definitively, it may be deduced that the laws of electro-magnetic maxima, on circuits to which shunt-circuits are

attached, are the same as for simple circuits, but only by supposing that the resistance R, on which they are based, is represented by the total resistance of the external circuit with its shunts, and by admitting that this total resistance is considered as if the battery were substituted for the electro-magnet in the circuit. And as the total resistance of a circuit from which shunt-circuits are taken is less than its own resistance, the helix should have less resistance than this latter.

If E in the preceding formulæ is expressed by the electromotive force of a Daniell element taken as unity, and if R is evaluated in metres of telegraph wire, $K = 0{\cdot}172175$, and the figure obtained represents fractions of a unit.

When referring the values of K and R to the British Association unit—that is to say, to the volt and ohm—$K = 0{\cdot}015957$.

In conclusion we would call attention to the fact, already mentioned in a previous chapter, that other things being equal, the strength of M and A also depends on the quality of the iron employed.

CHAPTER XI.

INSTRUMENTS FOR MEASUREMENTS IN CONNECTION WITH ELECTRIC GENERATORS.

Believing that a short description of a few of the most useful instruments for carrying out measurements in connection with electric generators will form a welcome supplement to our book, we have selected the dynamometer, the am-meter and the volt-meter, of Professors Ayrton and Perry.

By this selection we do not mean to imply that the instruments named are those only useful; for, amongst others, the electro-dynamometer and the torsion galvanometer of Siemens, as well as the ampère-meter and volt-meter of Marcel Deprez are also excellent instruments.

Ayrton and Perry's dynamometer. The Ayrton and Perry dynamometer is constructed as follows:

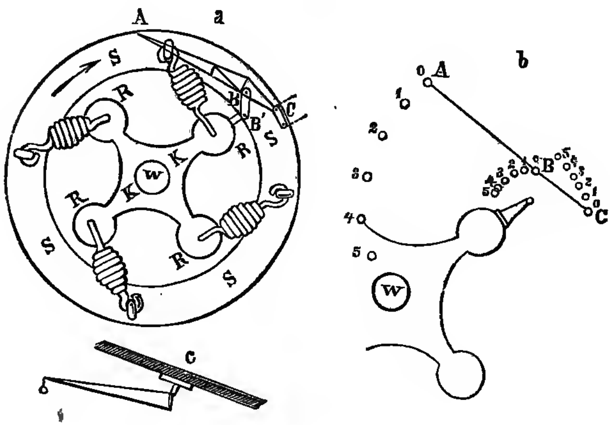
A cross-shaped piece *KK*, Fig. 51, is wedged on to the shaft *W* of the motor that drives the electric generator, and the four ends of this cross-piece *R* are connected, by strong spiral springs, with a pulley which transmits the power. When the transmission is made by means of belts, *S* represents a belt-pulley slipped loosely over the shaft; whereas if the shaft, to which the work has to be transmitted, lies in the continuation of the shaft *W*, *S* is firmly fastened to it.

Now, if *W* is turned in the direction of the arrow, the motion is transmitted to *S* by means of the springs; and the larger the amount of work transmitted the more are

the springs extended, thus causing the relative positions of K and S to be changed.

At C a small bar ABC is attached to S. From Fig. 51a it will be seen that this bar is supported against a point in the plane of rotation, and from Fig. 51c that it is supported against a point perpendicularly to this plane, and is connected with a continuation of one of the pieces R by a small bar BB'. Now if, during the rotation, S

Fig. 51.



lags a little behind W, A will approach the shaft, and the greater the amount of work transmitted the greater will be this approach; so that the positions 0–5 shown in Fig. 51b, indicate various degrees of this approach.

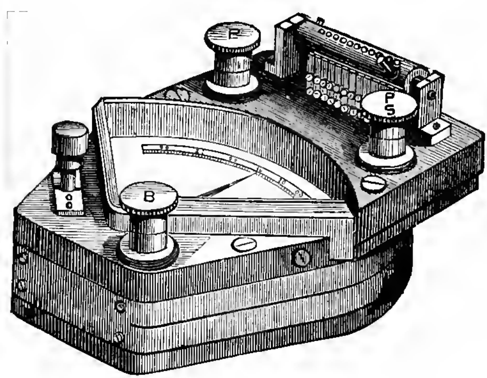
In order to make the position of the bar ABC visible to the eye, during the rotation of the machine, a small bright button is attached at A. When the rotation is rapid this describes a luminous circle, and the radius of this circle, which is a factor in the measure of the work transmitted,

can be read off from a scale placed on a level with the shaft.

If the number of revolutions, which is important as the other factor in the measurement, is known, it is easy to calculate the amount of work transmitted.

A great advantage of this dynamometer is that it occupies only a comparatively small radial space, and, according to the inventors, it costs little more than a

Fig. 52.



flange-coupling usually employed in connecting two shafts.

Ayrton and Perry's am-meter and Volt-meter. The **commutator am-meter** is an aperiodic galvanometer, obtaining its name from the circumstance that the strength of current can be read off from the scale directly in "ampères." Am-meter is an abbreviation of ampére-meter. It is connected with a commutator, which allows of the 60 convolutions of wire of the instrument being coupled up either one following the other, or as ten

abreast. In the latter case the resistance of the circuit is only $\frac{1}{100}$ of the resistance in the first case.

The following is the construction of the apparatus, which is shown in Fig. 52.

A small magnetic needle, connected with a light aluminium pointer, moves in the strong field of a powerful horse-shoe magnet; the coils of wire are arranged in such a way that the deflections of the needle, and, therefore, of the pointer, are proportional to the strength of current.

In order to gauge or to graduate this galvanometer, the commutator is turned so that the 60 turns of wire are connected in series, and a cell, of which the electromotive force, E, is known, is then connected with the binding-screws B and PS; the position of the pointer is then read off; call it S. By removing a plug, shown on the left in the figure, we insert a resistance of one ohm, which is connected with this circuit, and take a second reading; call this second reading G_2. The resistance of the instrument, together with that of the cell and of the conducting wires is, then—

$$\frac{G_2}{G_1 - G_2}$$

and the strength of current necessary for the first deflection is—

$$\frac{E\,(G_1 - G_2)}{G_2} \text{ ampères.}$$

We accordingly find strength of current in ampères, which corresponds to a deflection of any number of degrees, by multiplying the reading by

$$\frac{E\,(G_1 - G_2}{G_1\, G_2},$$

when the convolntions of wire in the am-meter are coupled up for intensity; or by

$$\frac{10\,E\,(G_1 - G_2)}{G_1\,G_2},$$

when the convolutions are coupled up for quantity.

If for instance in graduating we use a Leclanché cell (large pattern) of which the electromotive force is 1·26 volts, and the first reading gives us 6·2°, whilst after inserting the resistance of 1 ohm the pointer indicates 4·25, then the resistance is $\frac{4{\cdot}25}{6{\cdot}5 - 4{\cdot}25} = 1{\cdot}53$ ohms, and the strength of current for the deflection of 6·5 is $\frac{1{\cdot}26}{1{\cdot}53} = 0{\cdot}83$ ampères; accordingly, to deflect the pointer one degree, a current equal to $\frac{0{\cdot}82}{6{\cdot}5} = 0{\cdot}125$ ampères is necessary, when the convolutions of wire are coupled up by the commutator, one following the other, and equal to 1·25 ampères when they are coupled np, parallel or abreast.

Some of the Ayrton and Perry instruments are so constructed that, when the wire turns are coupled up abreast, one degree of the scale measures 1 ampère; whilst in others 1 degree means 2 ampères, in some even 5 ampères. With the latter instruments currents of more than 200 ampères can be measured.

Although the greater sensitiveness of the commutator am-meter, when arranged with its coils in parallel circuit by the action of the commutator, was originally only designed by the inventors for the purpose of graduating the instrument, it is now taken advantage of for determining small strengths of current of 0·5 to 2 ampères that occur in measurements with single incandescent lamps.

The commutator-volt-meter is a modification of the

instrument just described; the resistance of the coils of wire is 400 ohms (each of the ten coils = 40 ohms), when coupled up in series, and 4 ohms when coupled up abreast; whereas in the am-meter the resistance is only 0·3 when the coils of wire are coupled up in series, and 0·005 when coupled up abreast. Some of the volt-meters now constructed have a resistance of 200 ohms per coil, and accordingly when coupled up abreast, the parallel resistance is 20, and when in series, the resistance is 2,000 ohms.

Whilst the am-meter is graduated when the coils of wire are in series, and is usually employed in practice with the coils arranged parallel, the volt-meter is graduated with the coils parallel, and is used coupled up in series. In some instruments one degree corresponds to one volt, in others to five volts, so that by a complete deflection of 45° in the 5 volt instrument, the needle indicates an electromotive force of 225 volts.

But, as the am-meter can be employed, if necessary, with the coils of wire in series (when, for instance, we wish to measure currents of comparatively small quantity that occur with single incandescent lamps), we can also in exceptional cases employ the volt-meter with the coils of wire coupled up parallel; as for example, when we wish to measure electromotive forces of only 2 to 3 volts, as with accumulators.

In order to graduate the volt-meter, we couple up the coils of wire parallel, by means of the commutator, and then conduct a current through them from a cell whose electromotive force, E, is known. We take a reading of the deflection, and then remove the plug seen at the left hand of the figure. This inserts a resistance, equal to 4 ohms in this instrument. We then take a second reading.

The electromotive force corresponding to one degree is

$$\frac{10\,(G_1 - G_2)}{G_1\,G_2}\,E$$

when the turns of wire are coupled up parallel, and

$$\frac{G_1 - G_2}{G_1\,G_2}\,E$$

when they are coupled up in series (the usual arrangement of the coils of wire in the instrument).

The construction of the am-meter and volt-meter is such that in the am-meter the artificial resistance can be inserted only when the coils of wire are coupled up in series by the commutator; whilst in the volt-meter this insertion is possible only when the coils of wire are connected parallel. In this way damage to the resistance coil by fusion is avoided. In order to protect the galvanometer coils of the instrument against fusion — which might easily occur when the instruments are arranged for measuring currents of small quantity in the one case, or low intensity in the other — each instrument is provided with three binding-screws, marked *B*, (*P S*), and *P*, in the figure which will represent either a commutator am-meter or a commutator volt-meter, as both have exactly the same form.

In the am-meters of the latest construction, *P* can be used only for thick wires, and *B* only for thin wires, whilst (*P S*) is alone suitable for both kinds of wire; consequently the wires of an electric generator can only be connected with (*P S*) and *P*, and not with *B*; and as a current can only flow between (*P S*) and *B*, when the coils of wire in the instrument are coupled up parallel, it will be interrupted in the case where the coils of wire would be accidentally coupled up in series; in this way the

instrument is kept from injury by fusion of the wires, or by the needle being too strongly deflected.

Similar precautions are taken in the construction of the volt-meter.

The coiling of the wire of these instruments is such that the needle is deflected towards that binding screw which is in connection with the positive pole.

Am-meter and volt-meter without commutator. In large establishments using electric lighting where many am-meters and volt-meters are constantly employed, it is of course unnecessary that each instrument should have its own arrangement for graduation. It is sufficient to have a few of the instruments with commutators, and the others can then be compared with these; accordingly am-meters and volt-meters without commutators are constructed.

All these measuring instruments by Profs. Ayrton and Perry are constructed in such a way that the magnetic needle and the pointer swing on pivots, the axis passing through the centre of gravity, so that the deflection of the needle, and of the pointer, will be the same for any position of the instrument. The construction of the pivots is similar to that in watches; it is so fine that the friction is not increased by giving the instrument a slanting position. The permanent magnets of the instruments are sufficiently strong that the deflections of the needle are not easily affected by the proximity of electric machines.

One disadvantage which has been felt in the use of the instrument described is that the magnetism of the permanent magnets becomes in time modified by the electric currents. This would not be of importance if the instrument were always graduated with a Daniell cell; but Daniell cells are not always to be obtained at places where

the am-meters and volt-meters are employed, and the fact that graduation is necessary is prejudicial to the value of the instruments.

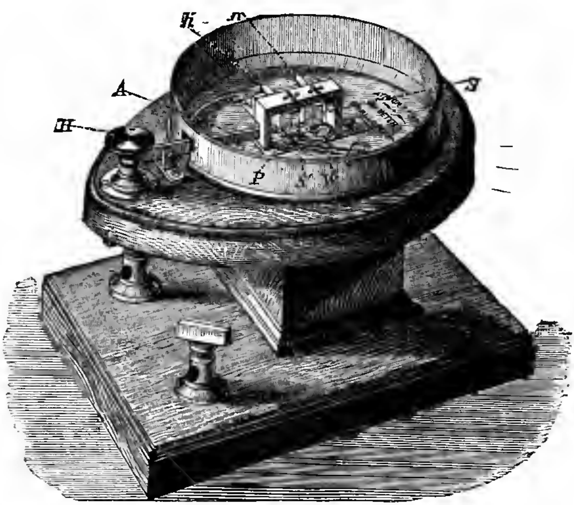
To prevent the weakening of the magnetism of the permanent magnets, the inventors have added a keeper to be put on when the instruments are not in use; later, however, the employment of permanent magnets has been given up and, **am-meters and volt-meters with springs** made. In these instruments the needle is not controlled by the pole of a magnet, but by a flat or cylindrical spiral spring, and the soft iron needle makes an angle with the axis of the galvanometer coil, which is less than 90° when the instrument is at rest (an angle of 90° would disturb the aperiodic character of the instrument). The inventors have determined by a large number of experiments and by calculation, what angle the needle must make with the axis of the galvanometer coil (when the pointer is at 0°) in order to obtain the best results.

When these new instruments are well made, deflections up to 45° can be obtained, which are directly proportional to the current; and the instruments of this construction have the advantage that they can be used for alternating currents, and by a simple adjustment of the spring (by turning a small pointer moving over a scale), we can set the large pointer in such a way that in the am-meter it does not quit the zero position until the current has attained a certain strength, and in the volt-meter until it has attained a certain electromotive force.

This method, which permits of the spring being adjusted, and the degree of adjustment read off the scale, considerably increases the sensitiveness of the instrument. Let us assume for instance that with a particular instrument we have to measure currents of about 30 am-

pères or of a strength varying from 25 to 35 ampères. In this case we do not adjust the needle so that weaker currents will deflect it, but so that the pointer quits the zero position only with a current of 25 ampères. If the instrument were so adjusted that the deflection commenced with a current of 1 ampère, the 45 degrees would be distributed to 35 ampères; assuming 35 ampères to be

Fig. 53.



the maximum of the currents to be employed: in other words, each increase of 1 ampère in the strength of current would deflect the needle 1·3 degrees further whereas if the deflection of the pointer is made to commence with 25 ampères, the 45 degrees are distributed to 10 ampères; or 4·5° to each ampère. The sensitiveness of the instrument is, therefore, nearly four times greater than in the first case.

Instruments allowing of still more accurate measurements are the

Am-meter and volt-meter with cog-wheel and gear.—In this instrument there is a very fine cog-wheel *W* (Fig. 53) in the axis of the magnetic needle, and the teeth of this engage in the gearing *P* on the axis of the pointer. By this arrangement the deflection of the pointer is made ten times that of the magnetic needle, and if the construction of the instrument is such that up to 36 degrees the deflections of the needle are proportional to the strength of current, 360° of the pointer's deflection will have this proportionality. Besides this, the axis of the needle, as well as that of the pointer, is connected with a very sensitive spiral spring *S* and *S'* respectively. These springs can either be used simultaneously in carrying out the adjustment, or only one of them may be allowed to act; *S'* can be freed from the gearing by means by the lever *A* and screw *H*.

When the springs are equally strong, we can increase the sensitiveness of the instrument exactly a hundredfold by turning this screw, *H*, and freeing *S'*. This sensitiveness may be adjusted to a greater or less degree by bringing the strength of the spirals into certain relations.

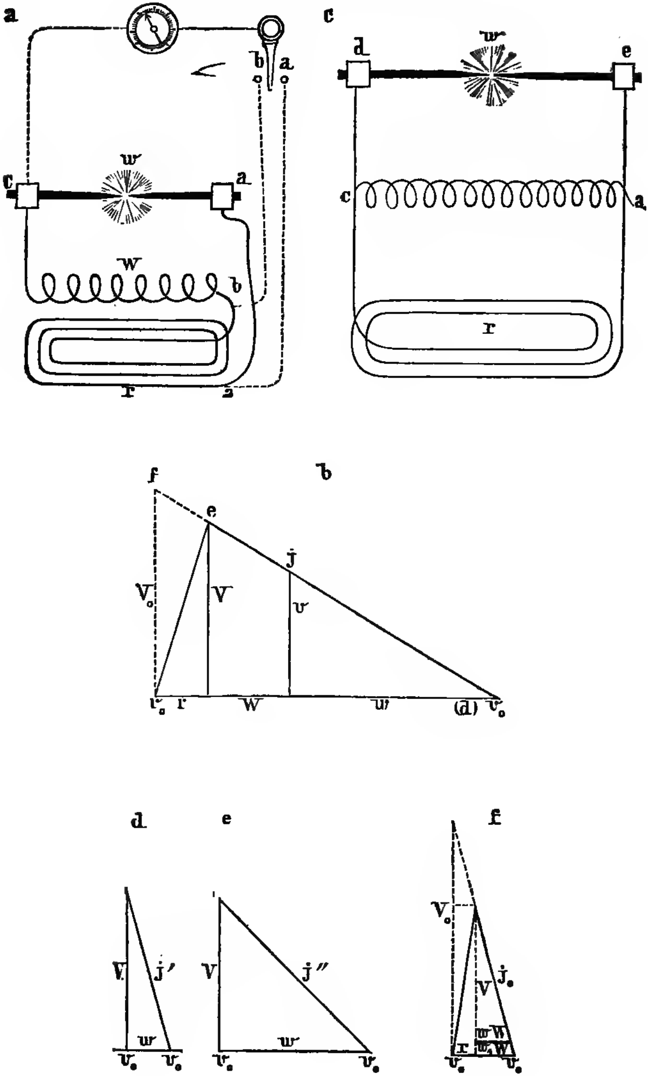
To each spring there is attached a small pointer, allowing of such an adjustment of the instrument that a comparatively few units of current in the one case or of electro motive force in the other, can be distributed over the 360 degrees deflection of the principal pointer. This is, for instance, desirable when small variations of a tolerably uniform current have to be measured; and by means of this construction of the am-meter and volt-meter, we obtain instruments that, although intended for large currents, or of high electromotive force, are as accurate and

sensitive as the more delicate instruments specially made for measuring weak currents and low electromotive forces.

Another instrument for measurements in connection with electric machines is the **horse-power measurer**, or **ergometer**, the scale of which is graduated for readings of horse-power, or $\frac{e^{\text{Volts}} \, i^{\text{Amp.}}}{746}$; and, therefore, simultaneously measures the strength and electromotive force of the current. We shall not, however, describe this instrument, although it is very useful in some cases, nor the **ohm-meter**, for measuring resistance in ohms, because the apparatus described are quite sufficient for all the measurements that usually occur in practice. And we shall conclude this section by stating a few physical equations for finding the principal values in the measurements usually to be carried out.

Equations occurring with measurements in connection with electric generators.—In order to calculate the work done in the various parts of an electric machine, as well as in the external circuit, the equations given by Dr. A. Jobler, of Zürich, may be used with advantage.

Let r be the resistance of the armature, W that of the electro-magnets, and w the resistance of the external circuit, in which, for instance, a number of electric lamps of unknown resistance are inserted. The resistance of the latter will usually be sufficiently great that the resistance of the conducting wires may be neglected. In Fig. 54, the resistances are denoted by the abscissae, and the potential by the ordinates; the *slope* of the straight line (f) (d) *or* J, accordingly represents the quantity of current C; a and b denote the terminals of the armature coil; a and c those of the generator; and a and (d) correspond to the same pole of the generator.


a
b a
w
c a
W
b
r
a
c
w
d e
c a
r
f b
e
j
V
v
r W w (d)
d e f
V j′
w
V j″
w
V j
r

In the expressions for the various differences of potential, V_0 is assumed to be equal to o, and $V—v_0$, for instance, denotes the difference of potential between the armature terminals, whilst $v—v_0$ denotes that between the poles of the generator, and V_0 represents the total electromotive force.

From Fig. 54 *b*, we can then deduce the following geometrical relations:

$$\frac{V_0 - v_0}{r + W + w} = \frac{V - v_0}{W + w} = \frac{v - v_0}{w} = (\text{slope of } J) = C. \quad (1)$$

$$\frac{V_0 - v_0}{V - v_0} = \frac{r + W + w}{W + w}; \quad \frac{V_0 - v_0}{v - v_0} = \frac{r + W + w}{w};$$

$$V_0 - v_0 = \frac{r + W + w}{W + w}(V - v_0) = \frac{r + W + w}{w}(v - v_0). \quad (2)$$

$$\frac{V_0 - V}{r} = \frac{V - v}{W} = \text{slope of } J = C. \quad (3)$$

$$\frac{V - v}{v - v_0} = \frac{W}{w}; \quad w = \frac{W(v - v_0)}{V - v}. \quad (4)$$

The work E, in horse-power, done in the above circuit, is obtained from the equation

$$E = \frac{C^2 (r + W + w)}{9{\cdot}81 \times 75} = \frac{V_0 C}{735{\cdot}75};$$

and, as according to equation (1), $v - v_0 = Cw$, we get

$$E = \frac{[C(r + W) + (v - v_0)]\, C}{9{\cdot}81 \times 75}.$$

The work e_1 lost in the wires, and the work e_2, obtained in the external circuit, can then easily be found by the aid of the equations

$$e_1 = C^2 (r + W)$$
$$e_2 = C^2 w.$$

The above formulæ, however, can only be used when the electro-magnet of the generator, in connection with which the measurements are being taken, is inserted in the main circuit; other formulæ are necessary for generators in which the magnet is inserted in a shunt circuit.

The diagrams, Fig. 54, *d*, *e*, *f*, will serve to determine the formulæ for such generators. Here, too, r denotes the resistance of the armature, W that of the electro-magnets, w the resistance of the external circuit, and $V - v_0$ the difference of potential between the terminals of the armature.

From the diagrams we then get—

$$\frac{V - v_0}{W} = (\text{slope of } j') = C'; \quad \frac{V - v_0}{w} = (\text{slope of } j'') = C'';$$

$$C' + C'' = C_0; \quad \frac{V_0 - V}{r} = C_0; \quad V_0 = C_0 r + V.$$

The reduced resistance of the electro-magnet coils and of the external circuit is

$$\frac{w\,W}{w + W}.$$

If this value is taken on the axis of the abscissae, we easily get C_0 and V_0 (Fig. 54 *f*).

The work, in horse-power, of the current, is then distributed as follows:

Total work:

$$E = \frac{(V_0 - v_0)\,C_0}{9{\cdot}81 \times 75} = \frac{C_0^2\left(r + \dfrac{w\,W}{W + w}\right)}{735{\cdot}75}\ H.P.$$

Work in the armature coils:

$$e = \frac{C_0^2\,r}{9{\cdot}81 \times 75}\ H.P.$$

Work in the coils of the electro-magnet:

$$e_1 = \frac{C'^2\ W}{9{\cdot}81 \times 75} = \frac{C'\ (V - v_0)}{9{\cdot}81\ \times\ 75}\ H.P.$$

Work in the outer circuit:

$$\frac{C''^2\ w}{9{\cdot}81\ \times\ 75} = \frac{C''\ (V - v)}{9{\cdot}81\ \times\ 75}\ H.P.$$

With the help of these formulæ and of Fröhlich's equations given in Chapter V., almost all measurements can be carried out that occur in practice in connection with magneto- and dynamo-electric generators.

CHAPTER XII.

LATEST TYPES OF GENERATORS.

ENOUGH has been said in the preface to show the direction in which during the past few years improvements have been made, but it remains before describing them to classify in some way the types of machines now in use. Generators are primarily specified as of the alternating or continuous class, accordingly as the current generated alternates in direction or flows in one direction only. We have consequently established to start with a classification which depends on the character of the current produced.

Alternating-Current Machines may be broadly divided into two groups, comprising (*a*), machines in which the armatures are fixed while the magnets revolve, and (*b*), machines in which the magnets are fixed while the armatures revolve. In the former group, the armature consists of a number of independent coils which may be in the same electrical condition at the same instant, or of coils grouped in two or more sets which may be at the same instant in different electrical phase. In the latter case, there must be as many circuits as there are sets of coils. All the coils of each set can be connected up together in parallel or in series, and the machine can thus be made to yield according to requirements, large currents of low e.m.f. or small currents of high e.m.f. In machines belonging to the second group, the individual coils of the revolving armatures are generally connected up in series or in parallel to suit the requirements of the circuit, the two ends of the one coil

thus formed being brought to two insulated rings on the spindle off which the current is collected.

Continuous-Current Machines: Adopting the suggestion of Professor S. P. Thompson, continuous-current generators may be described as belonging to the **open-coil** or **closed-coil** class accordingly as the e.m.f. is due to the sum or difference of a number of independent coils thrown into the circuit at intervals, or to the motion of a closed conductor from which the current is collected at two points diametrically opposite each other and fixed relatively to the magnetic-field. Of the former class, there are only two at present before the public, namely the Thomson-Houston and Brush machines. All the others described in this chapter belong to the closed-coil class.

Having classed machines, first according to the nature of the current yielded and secondly according to the way in which the current is collected, there remains a third distinction depending on the method of winding the armature. All continuous-current machines have armatures with iron cores, which are said to be **ring-wound** or **drum-wound** accordingly as the conductors pass through an interior opening, Fig. 27, or lie on the exterior surface of the core only, Fig. 34. To the former class belong the Raffard-Breguet, Goolden and Trotter, Manchester, Phœnix, Kapp, Crompton, Gülcher, Victoria and Elwell-Parker machines, while to the latter class belong the Edison-Hopkinson, Weston, Chamberlain and Hookham and Thomson-Houston incandescence machines. In consequence of the former class of armature having in some machines the greater dimension of the core at right angles to the spindle and in others the greater dimension parallel to the spindle, they have been termed respectively disc and cylinder armatures. The table on other side ex-

plains this classification of machines made with reference to the winding of the armature.

- **Continuous Current Dynamos.**
  - **Open Coil.**
    - **Ring-wound.**—Brush.
    - **Drum-wound.**—Thomson-Houston.
  - **Closed Coil.**
    - **Ring-wound.**
      - **Disc.**—Victoria, Gülcher.
      - **Cylinder.** — Raffard-Breguet, Goolden & Trotter, Manchester, Phœnix, Kapp, Crompton, Two-pole Gülcher, Elwell-Parker.
    - **Drum-wound.**—Edison-Hopkinson, Weston, Chamberlain and Hookham, Thomson-Houston incandescence.

Field-Magnets: Whether the magnetic-field is obtained from a large number of small magnets, as in the various

Fig. 55.

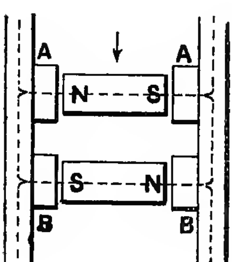


Fig. 56.

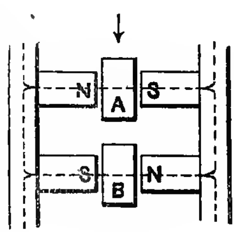
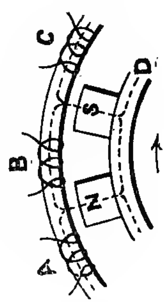


Fig. 57.



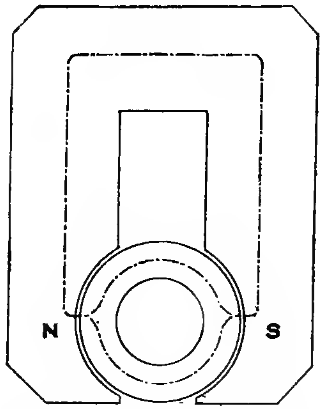
alternating-current machines, or from one large horse-shoe magnet, as in some machines giving continuous currents, the chief object of the designer is to make the magnetic resistance of the path through which the lines

of force flow a minimum. For this reason the magnetic circuit is mostly completed in iron, so that for a given excitement there is produced maximum magnetic induction.

The path which the lines of force take in the various alternating machines described is shown in Figs. 55, 56 and 57. In Fig. 55, *A* and *B* represent the armature coils of the Gordon generator, *N S* being the field magnets. The dotted lines show the closed magnetic circuits. In Fig. 56 are represented the armature coils *A B* and field-magnets *N S* of the Siemens and Ferranti generators, which have no iron in their armatures. In Fig. 57 are represented the armature coils *A B C* of the Gramme and Ganz generators, the former being wound and the latter laid on a ring of soft iron wire. These machines have radial revolving magnets *N S*, and the dotted lines show the magnetic circuits. The various forms of magnets employed in continuous-current machines are shown in Figs. 58-61. In Fig. 58, the magnet is a single horse-shoe, and the dotted lines show the path lines of force take. This form is employed in the Edison-Hopkinson, Kapp and two-pole Gülcher machines. In Fig. 59, the field is produced by two horse-shoe magnets wound so as to have their like poles together, one-half of the lines of force in the armature passing through each horse-shoe. This form is employed in most modern machines and has the advantage of being lighter than the single horse-shoe, although the weight of copper required to produce an equally strong field is greater in the latter case than in the former. As drawn, the weight of iron in the magnets of Fig. 58 is 1·5 times greater than in those of Fig. 59, the machines being for similar output and having in the magnet and armature cores the same density of force lines. These two forms are typical. All field-magnet systems belong either to the

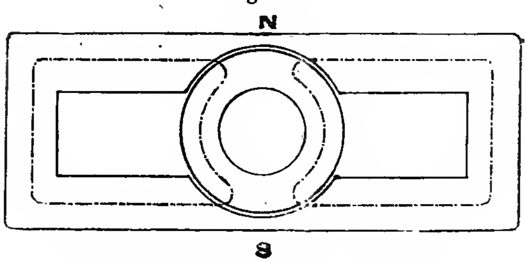
single-magnet or **double-magnet** class accordingly as they have for each pair of poles a single horse-shoe or two horse-shoes. In Fig. 60 is shown a four-pole machine of

Fig. 58.



2-POLE SINGLE-MAGNET.

Fig. 59.

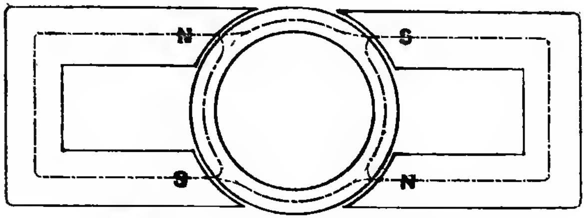


2-POLE DOUBLE-MAGNET

the single-magnet class, there being for each pair of poles only one horse-shoe. In Fig. 61, again is shown a four-pole machine of the double-magnet type each pair of poles

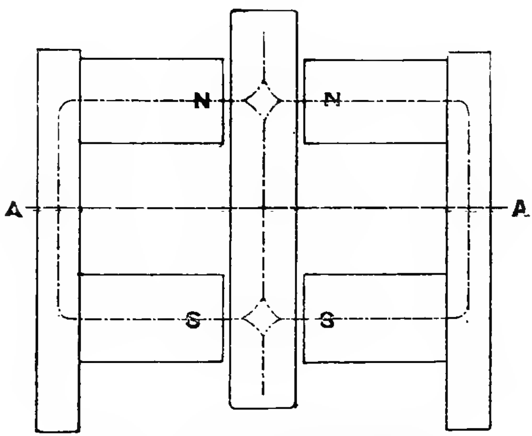
having what is equal to two horse-shoes, one on each side of the armature core. The dotted lines in both these last mentioned show the path of the lines of force. The field

Fig. 60.



4-POLE SINGLE-MAGNETS

Fig. 61.



4-POLE DOUBLE-MAGNETS.

magnets should be as short as possible consistent with ample cooling surface for the magnetising coils.

Pole-pieces: At one time massive pole-pieces were

considered requisite for high efficiency, but in several machines of modern build no pole-pieces are employed. The necessity for pole-pieces is purely accidental to the construction of the machine, their function being to convey from the magnet cores to the armature the lines of force without offering to their flow appreciable resistance and to present to the armature a large surface, so that the resistance of air-space is as small as possible. In Figs. 58, 59 and 60 no pole-pieces are shown, the magnets being bored out to obtain the requisite polar surface. In Fig. 58 the cross section of the magnet must not be diminished by boring out to less than half its original section, while in Fig. 59, the core might be cut through to a knife edge without influencing detrimentally the magnetic-field. In machines with cylindrical cores, pole-pieces are always employed in order that the requisite polar surface may be obtained; and from a study of the generators illustrated the reader will conclude that in the particular cases in which they are now employed it would be difficult to obtain without pole-pieces an air resistance sufficiently low for the economical working of the machine.

Armatures, Great attention is now given to the proper subdivision of the armature cores. In modern dynamos the cores are constructed of soft iron wire coiled on a frame of iron discs or washers laid close together and insulated from each other; or of iron ribbon coiled on a supporting ring with the adjacent convolutions insulated from each other. Not only must the core be subdivided to prevent generation of Foucault currents, but care must be taken that in the method of attachment to the spindle no circuit is formed which would allow such currents to flow. In some of the earlier machines, the power absorbed due to Foucault currents flowing in the driving attachments was

considerable, but the loss from this cause has been in modern machines almost, if not completely, eliminated.

Working Temperature. The temperature to which a dynamo, running continuously, will ultimately rise, depends primarily upon the ratio of the energy expended in heating its coils to the area of the radiating surface. This area would alone determine the temperature were the armature of the machine at rest, but a very considerable portion of the heat generated is due to magnetic friction in the armature core. From the facts that it is in rapid motion and that a current of air is frequently made to flow through its interior, much less radiating surface is required in the armature for each watt expended in heating its coils than is required on the field-magnet coils for each watt expended in excitation. The effective radiating surface for the magnets is considerably greater than the surface of the coils alone, as the whole machine gets gradually heated up in continuous running, the surface effective in dissipating the heat being thus expanded. The increase of surface due to this heating of the machine frame, it is, however, difficult to calculate, and it has been the author's practice to allow, for dynamos running under ordinary circumstances, a radiating surface on the magnet coils of 1·5 to 1·75 square inches per watt expended in heating them. For the armature coils, half this surface will be found sufficient if the internal ventilation is good. Where the machines have to work in hot, badly ventilated rooms, it is often advisable to double the surface just given. With a radiating surface of 1·75 inches per watt, the magnet coils have been found by the author to attain in continuous running a temperature 33° C. above that of the surrounding air. In the test for continuous running of a 16 unit Edison-Hopkinson machine the armature and

magnets attained respectively temperatures 61° C. and 18° C. above that of the air in the test room. A radiating surface of 1·75 square inches per watt for the magnets and 1 square inch for the armature will be quite sufficient if the dynamos are in well-ventilated rooms above ground, but for ship-lighting, or where the machines are underground and in close proximity to steam boilers and engines, the surface should not be less than 2·5 square inches per watt for the magnets and 1·5 for the armature.

Sparking at the Brushes. It is almost unnecessary to state that such clumsy devices as those illustrated on page 177 for the reduction of sparking have become things of the past. The amount of sparking in the best dynamos is now-a-days quite inappreciable, and this excellent result has been obtained by giving to the magnets a proper shape by reducing the turns on the armature so that the distribution of the field-lines is not seriously modified by the currents flowing in them, and by approximating the number of collector bars to the number of convolutions on the armature. In series machines, where the current in the magnets increases at the same rate as the current in the armature, adjustment of the brushes for different currents is seldom required, the lead being constant. In machines compounded for constant potential a slight adjustment forward, as the current increases, will generally be found necessary to avoid sparking; while in shunt machines, this adjustment, but to a greater extent, will always be required. Much depends on the way in which the brushes are set on the collector. These ought to bed fairly down all the way across the surface and have a contact width about equal to that of a bar and a half. The pressure of the brushes ought to be as slight as possible consistent with their being prevented from jump-

ing, and, with care, the wear of the collector in well-designed machines may be made exceedingly small.

In the Thomson-Houston dynamo, which is of the open-coil class, the brushes are, in order to effect the regulation, purposely placed off the neutral line. This is an exceptional case, for in all other generators the brushes are adjusted so as to make the sparking a minimum.

Weight, Size and Output. In the machines described, great differences will be found in the ratio of output to weight, and it may be well to explain briefly the circumstances upon which this ratio depends.

The electro-motive force produced by any dynamo may be expressed by the formula :

$$E = N \times a \times n \times p.$$

where E is the total e. m. f. in volts ; N the number of revolutions per minute ; a, the cross sectional area of the iron in the armature core in square inches ; n, the number of turns of wire on the exterior surface of the armature, and p, a coefficient depending on the degree to which the core is saturated. The value of p varies from ·000035 to ·000040 according to the type and make of machine, but its exact value for the machines described can easily be found by the student where the requisite data are given.

From the formula it will be seen that the e.m.f. depends directly on the speed of rotation, hence for a machine of given weight the total electrical energy developed per pound of material is proportional to the number of revolutions. Although the total watts produced are proportional to the speed, the waste in the machine remains constant if the weights of copper and iron are unaltered. We have, therefore, the electrical effi-

ciency reduced at a lower speed and increased at a higher speed. To illustrate this, let us suppose we have a machine which at a speed of 1,000 revolutions produces 10,000 watts total electrical energy. Of this amount let 9,500 appear between the terminals and 500 be absorbed in the machine. The electrical efficiency will then be 95 per cent. If the current density remains the same, this machine will, at 500 revolutions, produce 5,000 watts, but since 500 of these are, as before, absorbed in the machine, the electrical efficiency will now be $\frac{4500}{5000} =$ ·9 or 90 per cent. If the speed is further reduced, say to 250 revolutions, the total watts become 2,500 and the efficiency $\frac{2000}{2500} =$ ·8 or 80 per cent. We see then that in machines of similar size, having similar weights of copper and iron, the ratio of energy converted to total weight and to weight of copper increases directly as the speed, the output or energy appearing between the terminals increasing rather faster. We also see, that with this increase of output there is an increase in the electrical efficiency, although due to magnetic friction and Foucault currents the conversion efficiency may be somewhat lower.

Imagine now that in making a slow speed machine we are at liberty to increase the amount of copper, the iron part remaining as before. The electrical waste is made up of a portion in the armature coils and a portion in the magnet coils. If the iron part of the machine is to remain unaltered, it is very unlikely that the former can be reduced, since the only method by which this could be done would be by increasing the gauge of wire. For this we have no room, and we cannot therefore increase the efficiency so far as the armature is concerned. But with the magnet coils it is different. Here by increasing the weight of copper we can make the waste smaller and

compensate, to some extent, the lower efficiency consequent on the slower speed. In the example above, let us suppose that of the 500 watts absorbed internally 300 are spent in the armature and 200 in the magnets. If we put about twice the weight of wire on the magnets we can reduce the latter quantity to 100 watts, making the total loss therefore 400 instead of 500. At 500 revolutions the efficiency will then be $\frac{5000-400}{5000} = \cdot 92$ or 92 per cent instead of 90 per cent as formerly. Here by increasing the weight of copper we have raised both the output and efficiency.

But for slow speed machines of higher efficiency, it becomes necessary to effect a reconstruction by putting more weight into the iron part. Since, other things remaining the same, the e. m. f depends on the product of the armature core area and number of convolutions, it is evident that n may be diminished as fast as a is increased. With the diminution of n the efficiency rises, since the resistance is smaller; but it will be observed that a is nearly proportional to the weight of iron in the machine, since if a be increased the field-magnet cross section must be increased in the same proportion. It follows then that high efficiency machines are necessarily heavier than machines of low efficiency, which give at the same speed similar output: it also follows, that in machines of similar efficiency and output the ratio of output to weight diminishes more rapidly than the speed. Among the machines which follow will be found ratios varying from 5 to 12 watts per lb. of material employed; but the student will be able to place these different machines on a fair basis of comparison from the considerations above set forth.

In machines of similar type and of similar efficiency, it is found that the output is nearly proportional to the

weight, provided the speed of rotation is inversely as the linear dimensions, and that the machines are, in all cases, raised to the same temperature.

(1.) Alternating Current Machines.

The De Meritens Magneto Generator still holds its own for lighthouse illumination, and several machines of large size have been recently erected. The machine illustrated in Fig. 18 has an armature, consisting of one ring of sixteen coils, but in some of the later machines as many as five rings of twenty-four coils each have been mounted on the spindle side by side to form the armature. The two machines for the lighthouse of Tino had each five rings of sixteen coils and forty permanent magnets, ranged in five circles of eight. Professor Adams gives the following particulars of three machines, intended for lighthouse illumination, which he tested at the South Foreland in 1884. Each machine had an armature, consisting of five rings of twenty-four coils and sixty permanent steel horseshoe magnets, ranged in five circles of twelve. Each coil consists of four layers of wire, and is 27 millimetres deep by about 100 millimetres wide. The 120 coils, when coupled in parallel circuit for lighthouse work, have a resistance of about one-twentieth of an ohm. The diameter of the armature is 2 ft. 6 in., and the normal speed 600 revolutions per minute. The e. m. f. on open circuit, is about 75 volts, falling to 37 volts at the terminals, when a current of 135 ampères flows. The great fall in potential is to be attributed chiefly to the weakening effect on the magnets of the current flowing in the armature. The machines described are the largest De Meritens generators yet constructed.

The Gordon Generator, constructed by the Telegraph Construction and Maintenance Company, is an alternating

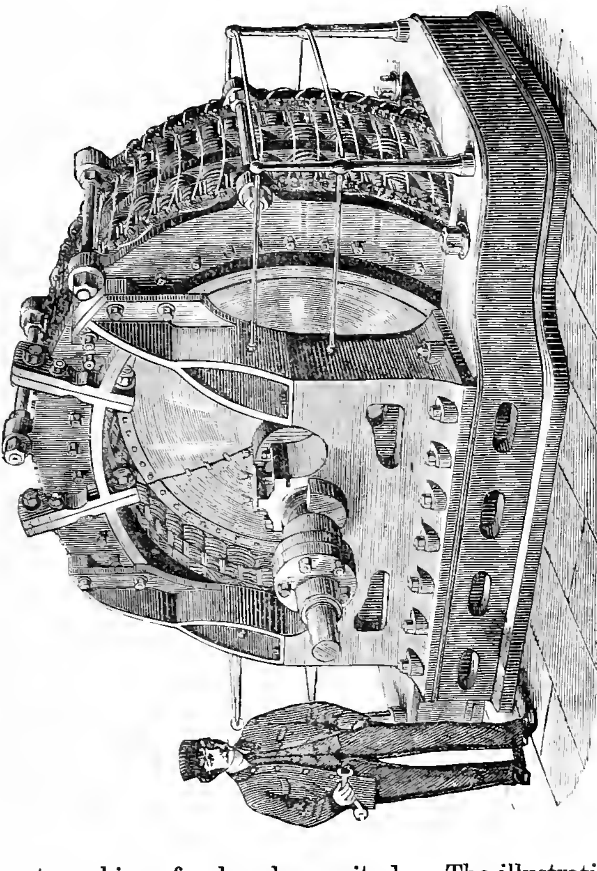
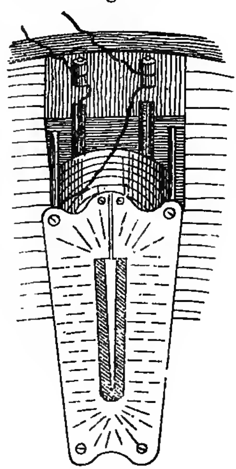


Fig. 62.

current machine of colossal magnitude. The illustration, Fig. 62, represents a machine said to be capable of supplying 5,000 Swan lamps, of twenty candle-power, at a speed of 140 revolutions per minute. Its weight, com-

plete, is 22 tons. Apart from its size, it will be seen that the Gordon machine differs in several points from that of Siemens', shown in Fig. 23. In the latter, the coils in which the currents are induced revolve and contain no iron; in the former, the coils in which the currents are induced are stationary and contain iron cores. In the Siemens' machine, the coils rotate between two circles of magnets; in the Gordon machine the field-magnets rotate between two circles of coils. The advantage of the latter arrangement lies in the facility with which the coils can be grouped to give, in the lamp circuit, a small current at a high difference of potential, or a large current at a low difference of potential. But, on the other hand, the revolving part is necessarily heavy, and there are good reasons for believing that machines of this type must be less efficient than those with revolving coreless armatures and stationary magnets. The magnets in the present

Fig. 63.



instance weigh 7 tons, and consist of thirty-two soft iron cylindrical cores, which pass right through the carrying rings and face with each end, but with opposite polarity, a fixed coil. The magnet wheel has a diameter of 8 ft. 9 in., and is constructed of wrought-iron plates, strongly braced together, and riveted to a substantial cast-iron centre-piece keyed on the driving shaft. The fixed coils are ranged in two circles of sixty-four on each side of the revolving magnets, their cores being formed of a piece of

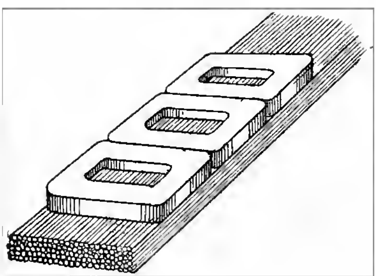
soft iron plate, bent back upon itself (Fig. 63). The coils are slipped on these cores, flanges of sheet German silver divided and slit as shown serving to keep them in their places. A screwed tail-piece is welded into the back of each core, and by these the coils are firmly secured to the cast iron frame which supports them, a thickness of wood intervening between the cores and the frame. It will be observed that there are twice as many fixed coils in the circle as there are field-magnets. By this construction only half the coils are active at once, and the weakening effects of mutual induction on neighbouring coils are avoided. As an exciter for this generator a Bürgin machine is employed.

The machine above described was constructed in 1882; but for a plant recently erected at Paddington, to give a supply equal to 30,000 gas lights, three Gordon generators of much larger dimensions have been laid down. Each of these machines weighs 45 tons, the rotating field-magnets weighing 22 tons. There are mounted on the magnet wheel, which is 9 ft. 8 in. diameter, twenty-eight magnets having cylindrical cores 3 ft. long by 6 in. diameter, the fixed coils being placed on each side of the wheel in two circles of fifty-six in each. Here an improvement on the former machine is apparent, the inducing portion in these later machines being much larger as compared with the induced portion. The machines run at a speed of 146 revolutions per minute, and are wound for a difference of potential of 150 volts. The exciting current is furnished by Crompton dynamos, driven direct by Willans' engines at 500 revolutions per minute.

Ganz's Generator, constructed by Messrs. Ganz and Co. of Buda-Pesth, is another alternating-current machine of gigantic dimensions. Constructed to supply current for

70 arc lamps and 600 incandescence lamps, it has a total weight of 15 tons, and runs at 180 revolutions per minute. The stationary coils, in which the current is generated, are of flat form, Fig. 64, thirty-six being laid side by side round the interior circumference of a wire drum. The thirty-six field-magnets are mounted on a ring inside this drum and form a fly wheel 8 ft. $2\frac{1}{2}$ in. diameter and 18 in. wide. These are similar in form to the revolving magnets of the Gramme alternating-current machine shown in Figs. 21 and 22. Mounted concentrically on the same shaft is the exciter, which consists of a six-poled Gramme ring of 3 ft. 11 in. diameter revolving between 12 pairs of field-magnets. The exciter generates a current of 88·8 amperes at a difference of potential of 36·4 volts. The alternating current is said to measure 1,516 amperes at a difference of potential of 57·6 volts, and the electrical efficiency of the exciter and generator combined is given as 85 per cent.

Fig. 64.



The Ferranti Generator on its first appearance four years ago was considered an alternating-current machine of some promise. The main point of difference between it and the Siemens' machine, illustrated in Fig. 23, lies in the construction of the armature, which is shown diagrammatically in Fig. 65. The latter is without iron, and consists of a continuous ribbon of copper, or of several ribbons in

parallel, formed into a zig-zag and separated, the adjacent folds from each other, by a strip of vulcanised fibre, wound

Fig. 65.

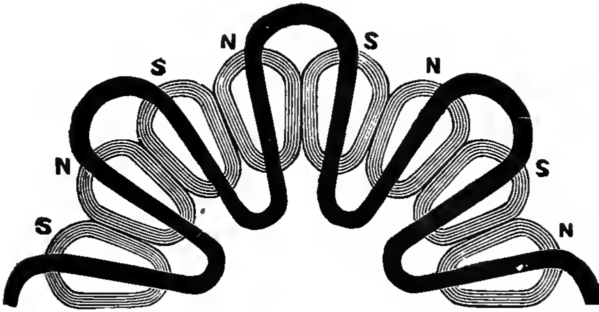
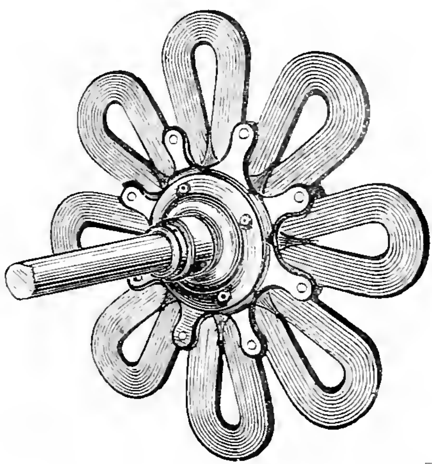


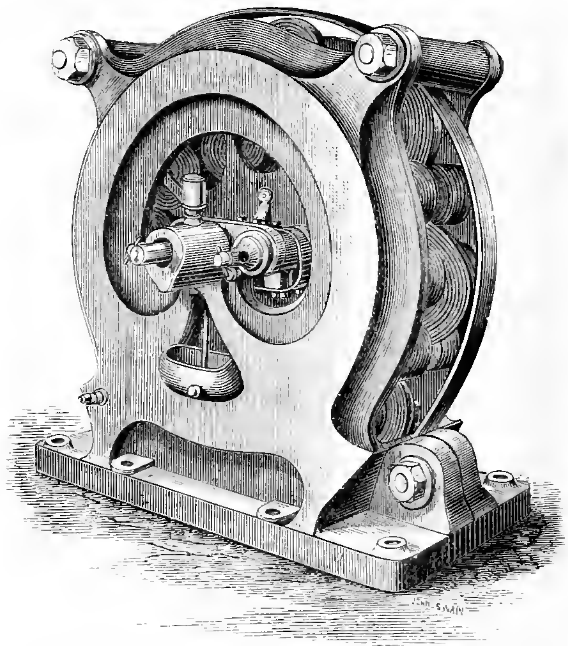
Fig. 66.



along with the ribbon. Two insulated rings on the spindle, to which the opposite ends of the ribbon are connected, serve to distribute the current through white metal rubbers

kept in contact with the rings by suitable springs. In Fig. 66 is shown the complete armature. The ribbon conductor is secured to the spindle by a phosphor-bronze hub through which pass muntz metal rivets, insulated from and lying in the hollows of the zig-zag. The complete machine is illustrated in Fig. 67, the carcass consisting of

Fig. 67.



two side checks of cast-iron on each of which are cast in a circle 16 pear-shaped magnet cores. These are magnetised by coils, afterwards placed on them, so that adjacent cores present alternately N and S poles, those coming opposite

when the checks are bolted together, presenting faces of opposite polarity.

The construction of the armature ought to be compared with that of the Siemens' machine before referred to. In the latter the armature is made up of separate coils secured to a central piece by German silver side plates, the result being a structure obviously inferior to that of Ferranti as far as strength and rigidity are concerned. There being no supports interposed between the moving conductor and the magnets in Ferranti's machine, the opposite magnet faces can be brought closer together and the necessary intensity of field produced by a smaller excitement. But given the same intensity of field and the same speed, the weight of copper in the armature necessary to produce similar effects is the same in both machines, the smaller weight of copper in the Ferranti being due only to the greater speed at which the armature rotates. The Ferranti machine for 1,000 lights of 20 candle-power has an armature 30in. diameter rotating at a speed of 1,400 revolutions per minute. The weight of the machine complete is 32 cwts., the armature weighing 96 lbs. The armature resistance is given as ·005 ohm. For exciting the magnets, a small continuous current Siemens' machine is employed as illustrated on page 44.

(2.) Continuous-Current Machines.

(Open-Coil Class.)

The Thomson-Houston Dynamo illustrated in Fig. 68, is an arc lighting machine which exhibits in its construction every shade of electrical heresy. Although most of the principles of correct design, or of design

hitherto considered correct, have been violated in its construction, it seems, disregarding the question of efficiency,

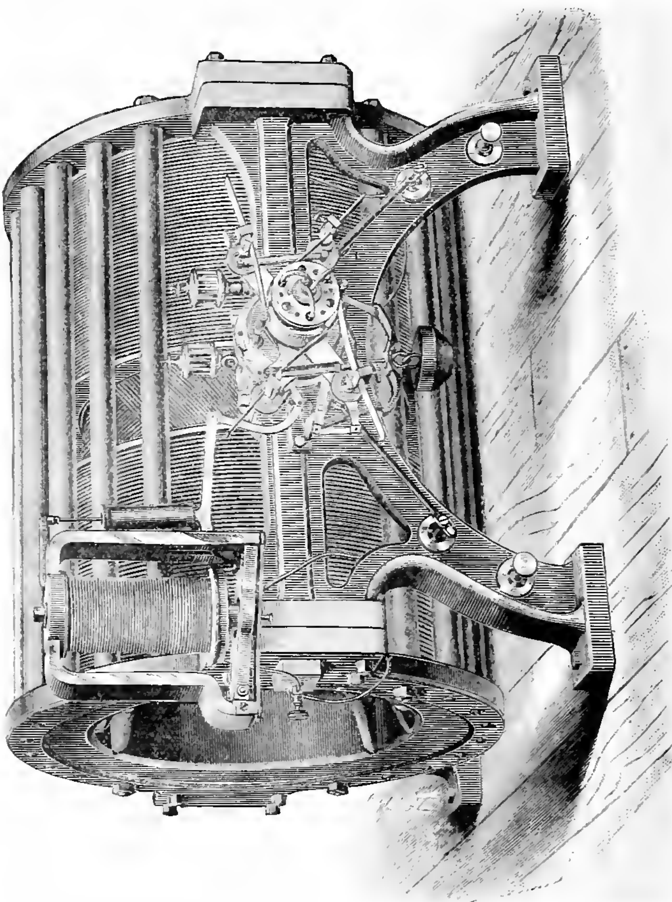
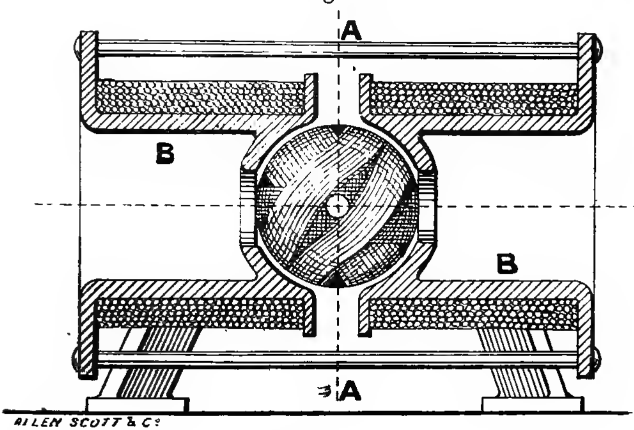


Fig. 68.

that a high degree of success has attended its working. It is largely employed in the United States, but has only recently been introduced into England. The armature,

externally resembling a sphere, is wound Siemens fashion with three coils. The coils are joined together at one end, the three free ends being connected up to three separate circular plates having each an angular width of 120°, and which when mounted on an insulating piece end to end and separated by an air space form the commutator. The armature core is of soft iron wire, coiled on a spheroidal frame, formed by a number of arched, wrought-iron bars

Fig. 69.

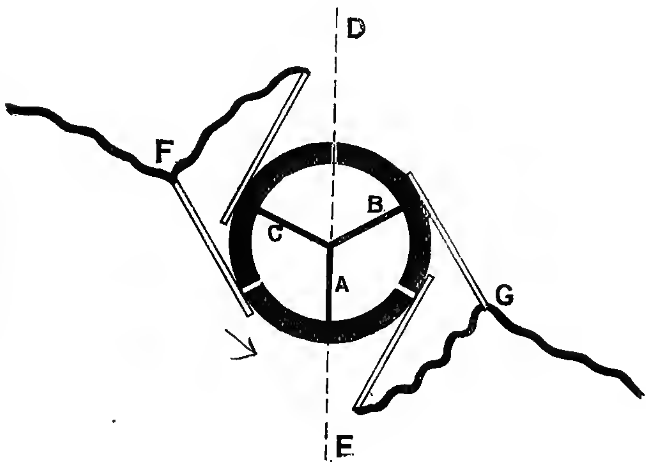


let into holes in the outer edges of two convex cast-iron plates keyed on the shaft some distance apart. In Fig. 69 is shown a section through the magnets. These consist of cast-iron tubes, *B B*, partially closed at the two inside ends, next the armature, which constitute the poles. Between the flanges on the outside ends stretch a number of yoke bars, *A A*, the exciting coils being wound on the outside of the cast iron tubes as shown. The action of the machine is as follows:—In Fig. 70 let the lines *A*, *B* and *C* represent the planes of the three armature coils, the

inside ends being joined together and the free ends attached to the three commutator segments as shown. The dotted line *D E* represents the neutral position, a coil when its plane coincides with this line being idle, or furnishing to the circuit no electro-motive force. The current is collected by what is equivalent to two brushes having an angular width of 60° under the normal conditions of working. This angular width is varied by a regulating apparatus in the main circuit, each brush consisting of two copper plates connected electrically. From the brushes *F* and *G*, the current is led through the regulator to the lamp circuit. Since each brush has an angular width of 60°, there is between the positive and negative brushes an angle of 120°, which is equal to the width of one commutator segment. It follows that from the time one segment touches till the time it leaves a brush, the armature must rotate through an angle of 180°, or make exactly half a revolution. In its normal condition then, each segment is always under one brush or the other, and changes over from the positive to the negative at the moment the corresponding coil occupies the neutral position, the current always flowing through one coil in series with two in parallel. Consider what happens in half a revolution from the time a segment touches till it leaves the brush. In Fig. 70, coil *A* is shown in the neutral position and just changing over from the left hand to the right hand brush. For 60° onwards from the position shown, *A* is in parallel with *B*, these two being in series with *C*. For the second 60°, *A* alone is in contact with the brush, but in series with *B* and *C*, which are in parallel. For the remaining 60° of the half revolution, *A* is in parallel with *C*, these two being in series with *B*. In other words, for one third of the

time the segment is under the brush its coil is in parallel with the one in front of it, for one third it is in series with the other two in parallel and for one third it is in parallel with the one behind it. It then passes to the next brush and the changes are repeated. It will be observed that a coil which is neutral is put

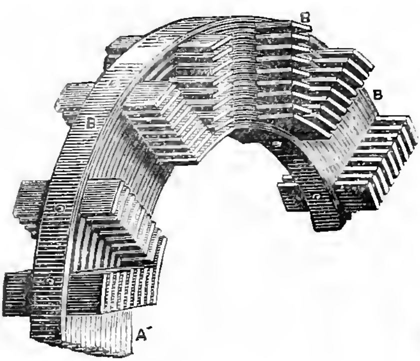
Fig. 70.



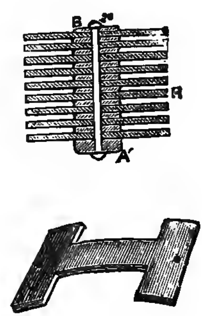
in parallel with an active coil when the latter has only moved 30° from its position of maximum activity, also that it is withdrawn from parallelism with an active coil when the latter is 30° from its position of maximum activity. Undoubtedly from this continuous short circuiting of an active with a neutral coil we have large local currents flowing, which must be a source of loss and to which is due a good deal of the sparking which occurs at the brushes. By an apparatus actuated by an electro-

magnet in the main circuit, the current is kept constant, the regulation being affected by increasing or diminishing the angular width of the brush, and giving to it at the same time a backward or forward displacement. If the current by the short circuiting of a number of lamps gets too great, the rear plate of the brush is moved backwards and the leading plate $\frac{1}{3}$ as much forwards, the effect of this being to bring the coil segments under the brushes

Fig. 71.



Figs. 72, 73.



before their coils become neutral and while yet they are active in an opposite sense to that in which they should be active in order to contribute to the e.m.f. of the circuit. By increasing the angular width of the brushes, the distance between them is made less than 120°, the width of a commutator segment. The two brushes, in consequence, touch one segment, and the result is that two active coils are short-circuited through a commutator segment six times in each revolution. If the current gets too low, the rear brush plate is moved forwards and the leading

plate backwards, the effect of which will be understood from what has been already said. The regulation of the machine is thus effected by an automatic determination of the fraction of a revolution for which the armature shall be short-circuited on itself and of the stage at which the respective coils shall be cut into parallel with coils more active. A blower is attached to the machine, which, by sending a puff of air at the right time against the point of the leading brush plate, blows out the spark. That the action of the machine will ever be completely understood seems highly improbable, from the complicated reactions taking place. The reader may be helped in his study by cutting out a three-segment collector in cardboard and rotating it on a sheet of paper, on which he can draw the brushes with various angular widths and displacements.

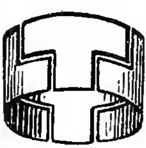
The Brush Dynamo of to-day differs from that shown in Fig. 24 chiefly on account of the cast-iron armature core having been abandoned in favour of the wrought-iron laminated core, part of which is shown in Figs. 71 to 73. This core is built up of thin wrought-iron ribbon, *B*, coiled on an interior ring, *A*, there being secured between the successive convolutions **I** pieces of iron of the same thickness as the ribbon, Figs. 72 and 73. These **I** pieces have webs equal to the width of the ribbon, the flanges consequently protruding beyond on each side to form the Pacinotti projections between which the coils are wound. They are held firmly in their places by radial rivets, which, in addition, serve to bind the whole armature securely together. The results obtained from this armature are a great improvement on those derived from the old cast-iron one, for at the same speed and with the same current, there is a gain of 30°/₀ in the e.m.f. Due

to elimination of eddy currents, which, in the older armature were made so apparent by heating, there is also a great gain in economy. It is stated that there is required, to drive the machines at the higher output above given, a less horse-power than was formerly required for the cast-iron machine.

Another difference in the modern machine lies in the fact that when coil is cut out of circuit it is opened at both ends, the commutator now employed being shown in Fig. 74. Formerly one end of the coil was, while cut out, left in contact with the brush, Fig. 26. Now, when cut out, it is completely insulated from the circuit.

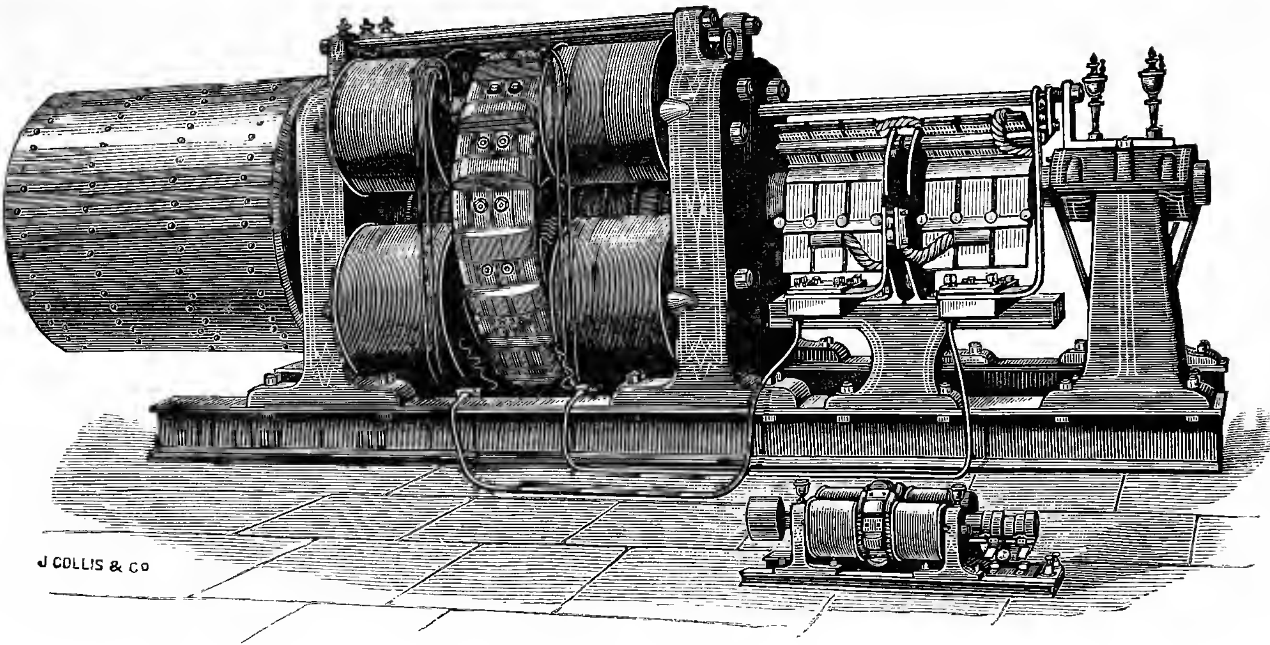
Lately a Brush machine of enormous magnitude has been constructed in America for the electric smelting of aluminium. This machine, which is shunt-wound, is shown in Fig. 75,* and weighs about $9\frac{3}{4}$ tons. There are eight field-magnets, each having a cylindrical cast-iron core, 11 in. diameter and 16 in. long. The armature is 42 in. diameter, the iron in it weighing 1,600 lbs. The weight of wire on the magnets is 5,424 lbs., that in the 16 armature bobbins being 825 lbs. The space occupied by the machine is 15 ft. long by 4 ft. wide by 5 ft. high, and the machine is said to furnish, at a speed of 450 revolutions per minute, a current of 3,200 amperes at a difference of potential of 80 volts.

Fig. 74.



* The Author is indebted to the proprietors of *The Electrician* for this engraving.

Fig. 75.—(*To face page 268.*)



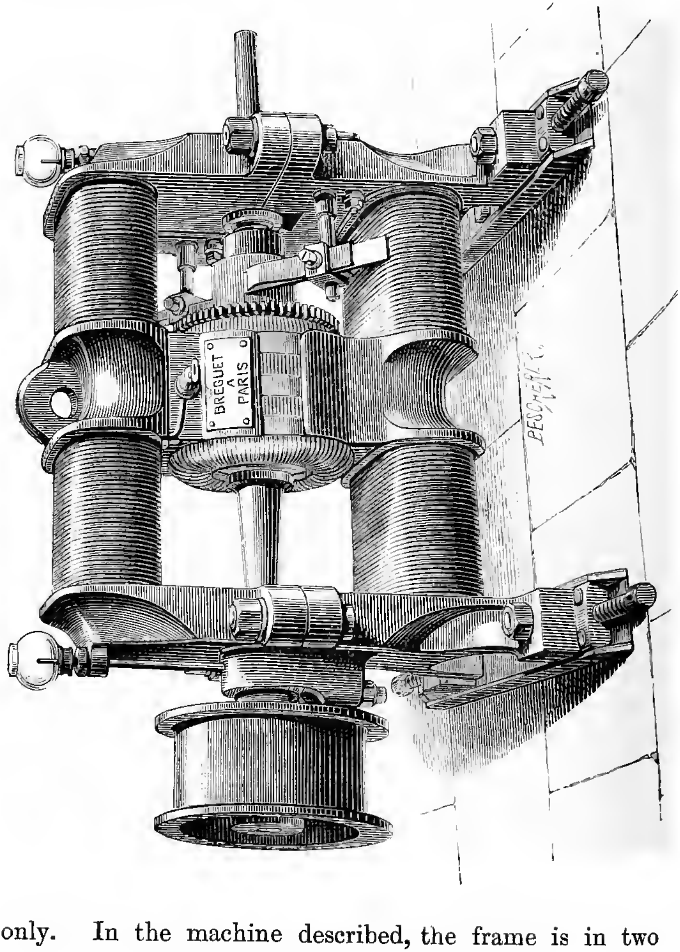
(3.) Continuous-Current Machines.
(Closed-Coil Class.)

The Raffard-Breguet Dynamo,* illustrated in Fig. 76, is manufactured by the Maison Breguet, and may be regarded as the latest development of the Gramme machine in France. Its configuration resembles that of the original machine, shown in Fig. 29, and the various modifications effected in its construction do not appear to have kept pace with those introduced by English makers. For the original armature core of soft iron wire, has been substituted one made up of soft iron washers about $\frac{1}{12}$ in. thick, separated by paper. The paper is thickly varnished and the varnish serves to hold the core together, until, by longitudinal taping, it is made rigid enough to receive the conductor coils. The core is 5 in. long by $4\frac{3}{4}$ in. internal and $7\frac{1}{2}$ in. external diameter. It is wound in the usual Gramme fashion with 23 lbs. of 87 mils. double cotton-covered copper wire, the coils being connected to a 60-part collector. The complete armature measures $8\frac{1}{2}$ in. in diameter. On the spindle is a twelve-sided cast-iron hub, and 12 wedges are driven in between this and the inner side of the armature to keep the latter in position. Whether this is an improvement on the older method of securing the armature is an open question, but in this country methods of driving by friction have been condemned long ago. All leading makers now in-

* For the illustration the author is indebted to the proprietors of *Industries.* In this excellent journal the first description in English of the dynamo appeared.

sist, and properly, that the armature core shall be firmly secured to the spindle by rigid mechanical connections

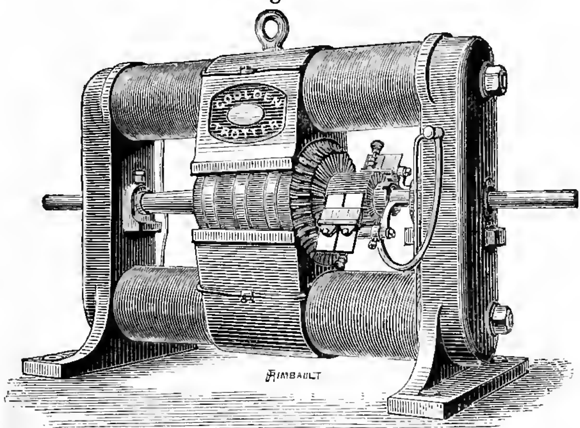
Fig. 76.



only. In the machine described, the frame is in two pieces, the magnet cores, pole-piece and half the yoke on

each side being cast in one piece. The magnet cores are of cast-iron, their lesser magnetic permeability, as compared with wrought-iron, being compensated for by excessive section. They are of oval form and measure $6\frac{3}{4}$ in. by 2 in., being series wound with 78 lbs. of 160 mils. wire. The total resistance of the machine cold is ·8 ohm. At a speed of 1,400 revolutions per minute, a current of

Fig. 77.

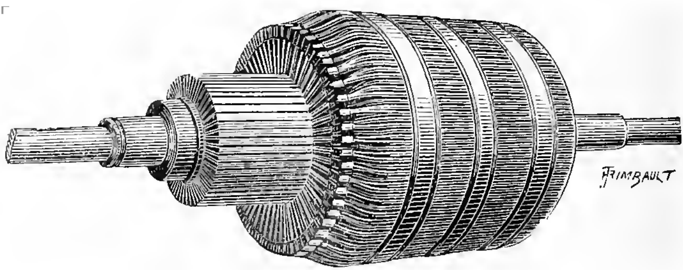


35 amperes is generated at a difference of potential of 110 volts. The over-all dimensions are, height, 22 in.; breadth, 14 in.; length, inclusive of spindle, which protrudes on each side, 33 in. The cast-iron frame weighs $3\frac{1}{2}$ cwts., the armature 65 lbs., and the whole machine a little over 5 cwts. The output is nearly 7 watts per lb. of material used in its construction.

The Goolden-Trotter Dynamo, shown in Fig. 77, resembles more closely than the machine last described the original Gramme shown in Fig. 29. Into its design,

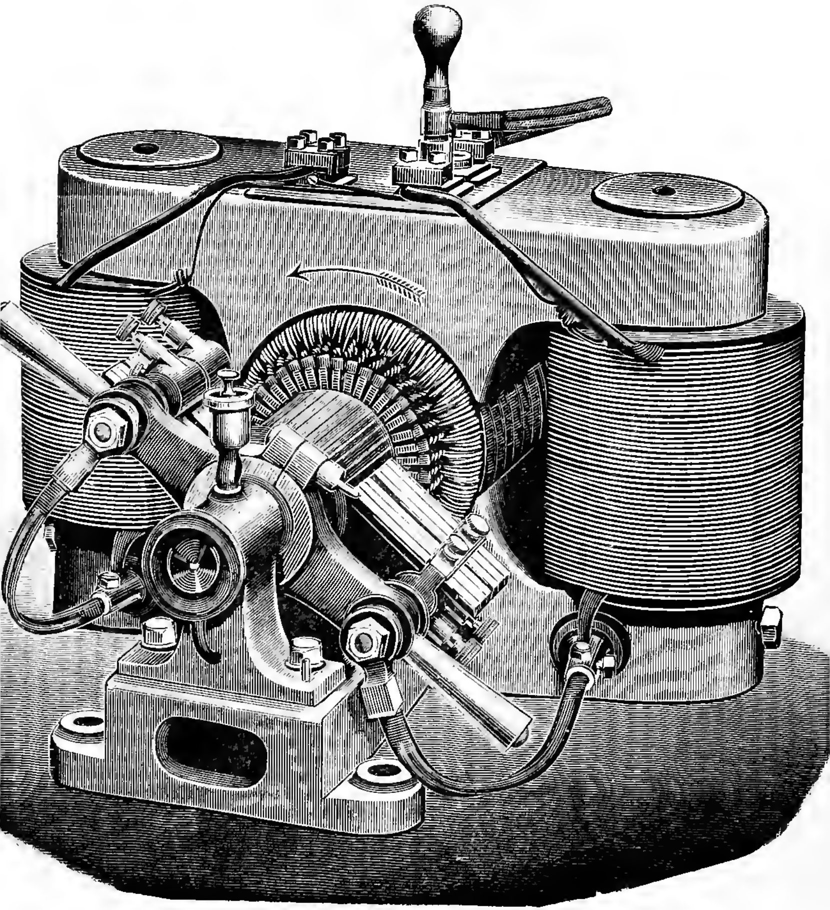
however, have been incorporated improvements which are common to all good modern machines. In place of the armature being driven by the friction of the internal wires pressing on a central hub, the iron core is attached to the spindle by gun-metal arms and driven in a positive manner, charcoal iron washers separated by paper having been substituted for the wire in its construction. In the Gramme machine, the area of the armature core was much smaller as compared with that of the field-magnets

Fig. 78.



than in the machine of Goolden and Trotter, the section of the armature in the latter being about two-thirds that of the magnets. The armature core is also thicker as compared with its length than in the Gramme machine. The cast-iron side checks receiving the wrought-iron magnet cores have been thickened up, and on these cores are fastened massive pole-pieces of cast-iron, between which the armature rotates. The armature is wound, Fig. 78, so that there is on the exterior surface only one layer of wire. The 12,000 watt machine runs at 950 revolutions per minute and weighs 2,464lbs., the output being at this speed rather less than 5 watts per pound of material used.

Fig. 79.—(*To face page* 273.)

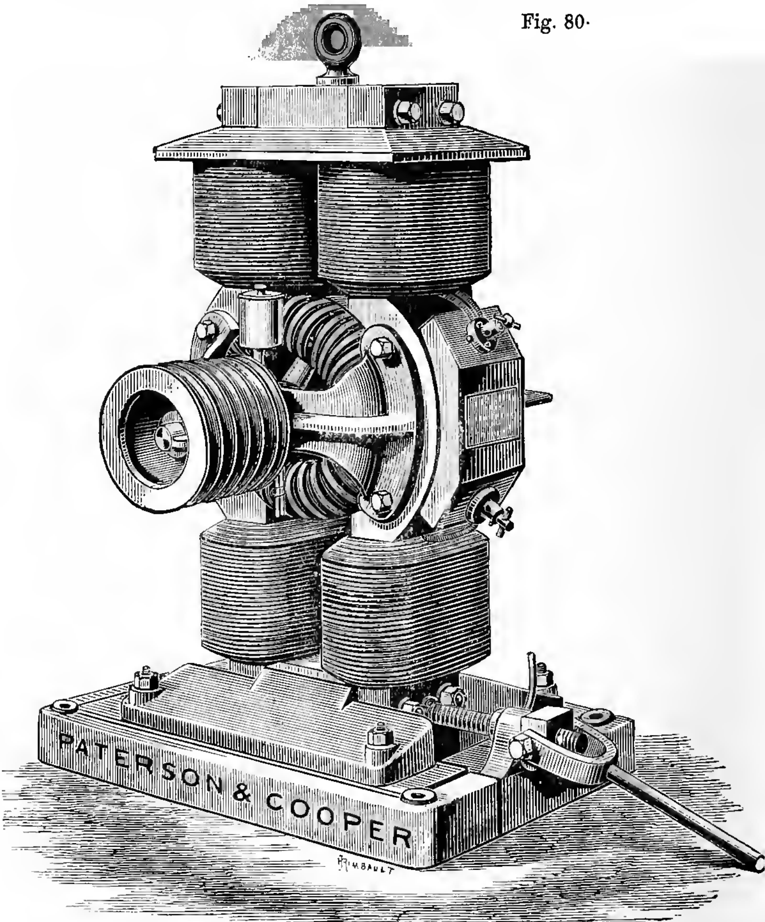


The Manchester Dynamo, recently introduced by Messrs. Mather and Platt of Salford, is shown in Fig. 79. The machine is of the two-pole double-magnet type and is interesting on account of the disposition of its magnet coils, these lying nearly at right angles to the line joining the points of contact of the brushes, instead of being parallel thereto, as is generally the case in double-magnet machines. The poles are formed of massive blocks of cast-iron, which are bored out and fitted on the wrought-iron cylindrical cores, the object of thus letting the cores into the cast-iron being to obtain a contact surface equal to twice the sectional area of the cores. The armature, which is Gramme-wound, has a core formed of charcoal, iron washers separated by paper, the coils, being joined up to a 40-part collector, having bars of drawn copper insulated by mica. The illustration is $\frac{1}{7}$ full size; and the machine, which is compound-wound for incandescence lighting, gives at a speed of 1,050 revolutions per minute 130 ampères at a difference of potential of 100 volts. Its total weight is 1,372lbs., the armature weighing 252lbs. The output is therefore 9·48 watts nearly per lb. of material.

The electrical data of a compound machine running at 1,050 revolutions and intended for a current of 200 ampères at 110 volts are given by the *Engineer* for Aug. 7th, 1885, as follows:—Armature: core, 12in. diameter; 12in. long, wound with 120 convolutions of wire 203 mils. diameter connected to a 40-part collector. Field-magnets: core $7\frac{1}{2}$in. diameter, compound-wound, and having on each limb 42 turns of triple 203 mils. wire and 1,680 turns of 65 mils. wire. Length of magnetising coils, $12\frac{1}{2}$in. The resistances are: armature, ·023 ohm; series coils, ·012 ohm; shunt coils, 19·36 ohms. The radiating surface of the field

double-magnet type is one of the latest designs for ship-lighting and is mounted on a cast-iron bed-plate fitted

Fig. 80.



with screw rope-tightening gear. The engraving is one-tenth full size and the machine weighs with the bed-plate

complete, 1,519 lbs., the output being 14,580 watts at 1,200 revolutions, with an electrical efficiency of 92 per cent.

In several of the Phœnix dynamos, the armatures are built up of charcoal plates, or washers with projections, as in Fig. 81, these when laid together forming a ring with protruding teeth, between which the conductor coils are wound, Fig. 82. In others, the armature is built up of plain washers, the core thus presenting a smooth exterior. The object of the protruding teeth is to lessen the resistance of the magnetic circuit and to produce the requisite field density with a less quantity of wire on the magnets. The dynamo here illustrated has a toothed armature, the plates being separated by paper and clinched together by insulated bolts passing right through the core, these latter being firmly secured by their projecting ends to gun-metal supporting wheels, which are keyed on the spindle. The armature is milled in 48 slots, in each of which is wound a coil having 6 convolutions of wire 148 mils. diameter. The coils are Gramme connected to a 48-part collector. The clearance between the armature projections and the polar surfaces is $\frac{3}{16}$ of an in., the magnets being bored out to $13\frac{3}{4}$ in., and the armature measuring, over the teeth, $13\frac{3}{8}$ inches. The armature core is 7 in. long by 2 in. thick measured from the bottom of the slots, the area of the iron in it being 12 square in. The arched magnet bars are 7 in. wide, corresponding to the length of the armature core, and 3 in.

Fig. 81.

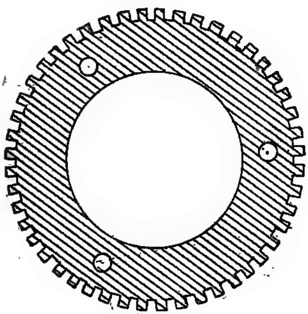
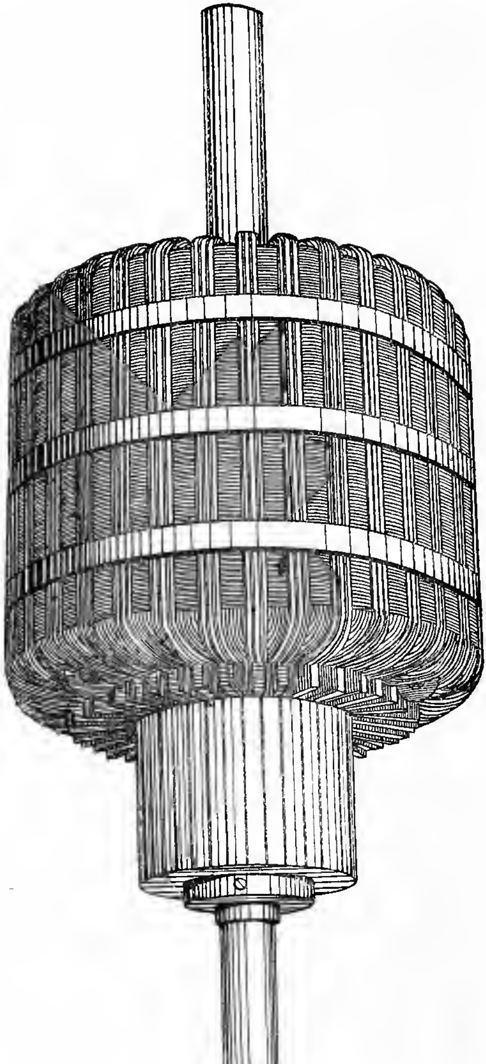


Fig. 82.



ARMATURE OF PHŒNIX DYNAMO.

thick, their area being 21 square in. At a speed of 1,200 revolutions per minute, a current of 90 ampères is delivered at a difference of potential of 162 volts at the terminals. The field-magnet coils present a radiating surface of 2·5 square inches for each watt expended in heating them.

The results tabulated below were obtained when a machine of this class was tested at the makers' works, the motive power being supplied by a Gwynne "Invincible" engine driving on to a counter-shaft, from whence was driven the dynamo. In the efficiency column is given the fraction of the I.H.P. actually available for lighting purposes.

PHŒNIX DYNAMO TESTS.

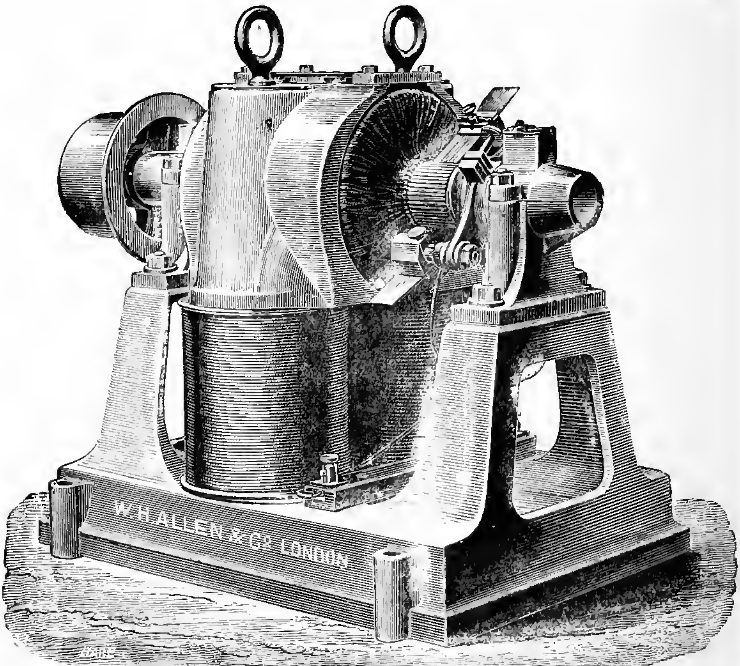
Revolutions.		I.H.P.	Amps. A.	Volts. V.	Watts. A. × V.	E. H. P. $\frac{A. \times V.}{746}$	Efficiency $\frac{E.H.P.}{I.H.P.}$
Engine.	Dynamo						
138	1205	26·90	88	166·0	14,608	19·58	·727
140	1244	26·14	85	168·0	14,280	19·14	·732
142	1256	27·65	85	170·4	14,484	19·54	·706
143	1260	27·16	83	170·0	14,110	18·91	·696
144	1270	27·71	85	172·0	14,620	19·59	·707
153	1370	28·33	79	191·2	15,104	20·24	·714

From the above it will be seen that the mean efficiency is ·713, or 71·3 per cent of the power expended in the engine cylinder can be obtained at the terminals of the dynamo.

In some of the later machines of Messrs. Paterson and Cooper's make, the output has exceeded 12 watts per lb. of material employed in construction, the speed of rotation being 1,200, with an electrical efficiency of over 90 per cent.

The Kapp Dynamo, manufactured Messrs. by W. H. Allen and Company, is shown in Fig. 83, $\frac{1}{12}$ full size. It belongs to the two-pole, single-magnet type, and is shunt-

Fig. 83.



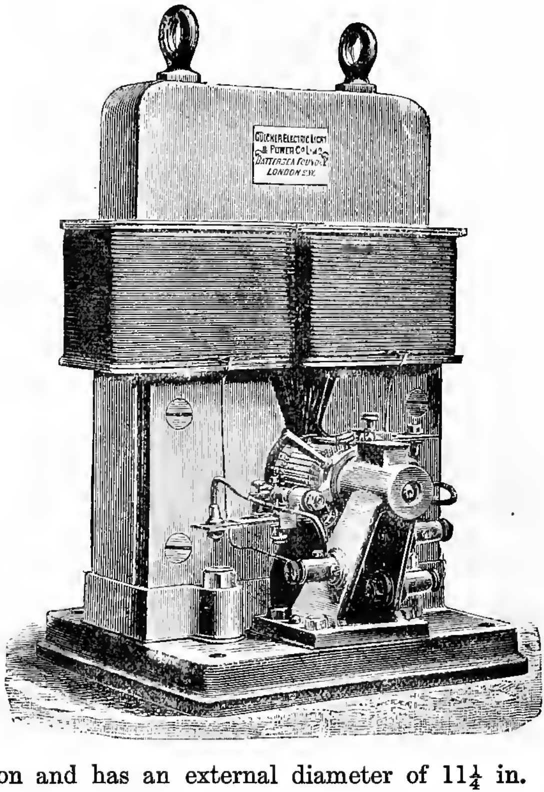
wound for a current of 125 ampères at a difference of potential of 82 volts. The machine weighs 24 cwts. and runs at a speed of 425 revolutions per minute. The field-magnets have wrought-iron cylindrical cores, their lower ends fitting into the bed-plate and their upper ends being turned taper to receive the cast-iron pole-pieces.

The armature is 13 in. long by 13 in. diameter, is Gramme-wound, and has a core made up of soft charcoal iron wire coiled on a gun-metal supporting cylinder, the latter resembling a number of double-flanged pulleys laid side by side and separated by a narrow space. The iron wire is coiled between the flanges, which have projecting from them, and rising above the iron wire, a number of teeth, transmitting, in a positive manner, the driving force to the conductors carrying the current. The air passing between the flanges, from the interior to the exterior of the armature, carries off the heat from the interior conductors and from the iron core. On the armature of the machine described, there are wound 216 convolutions of double 134 mils. wire, the area of the actual iron in the cross section of the core being 22·5 square in. The wire is two layers deep on the exterior, and the resistance, hot, is ·049 ohm. The cores of the field-magnets have an area of 75 square in., and the magnet-coils have a resistance of 16 ohms. The watts expended in the armature are 830, and the electrical efficiency is rather over 89 per cent. The radiating surface of the armature is nearly 1 square in. per watt.

The Two-Pole Gülcher Dynamo, shown in Figs. 84 and 85, is another machine of recent design belonging to the single-magnet class. It has a Gramme-wound armature, the core of which is formed by coiling on a gun-metal cylinder soft charcoal iron wire of rectangular section. The advantage of employing rectangular over round wire is two-fold; first, the length of conductor required per volt is considerably reduced, because the area of iron, enclosed by a given perimeter, is increased by 25 per cent.; secondly, an armature so constructed is mechanically strong, no flanges being required at the ends

of the gun-metal cylinder to keep the wire on. The core when completed is of square section and measures $3\frac{3}{4}$ in. each way. It contains in its cross section 12·6 square in.

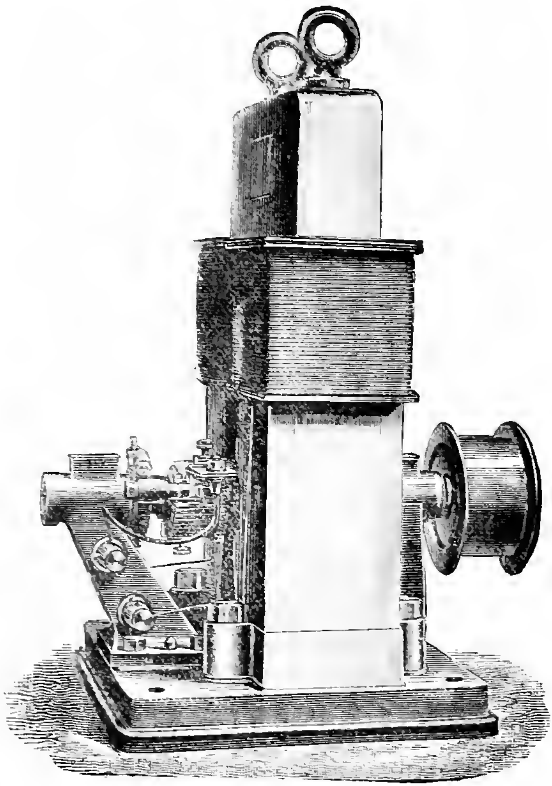
Fig. 84.



of iron and has an external diameter of $11\frac{1}{4}$ in. It is wound with 240 turns of copper wire of rectangular section 120 mils. by 83 mils. laid flatways, one layer deep on the external surface and five layers deep internally. The coils are connected up to a 48-part collector, and the armature

has, when hot, a resistance of ·077 ohm. The field-magnet rests on a gun-metal block interposed between the poles and the bed-plate, and is provided with wing-

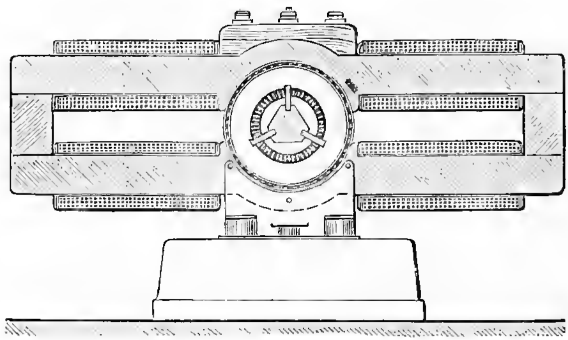
Fig. 85.



plates which enclose the armature on each side as shown. The cores of wrought-iron have a cross section of 25·5 square in., the area of the magnets and armature being consequently equal. The magnet-coils are $5\frac{1}{2}$ in. long,

the total weight of copper on the two being 43 lbs. The weight of copper on the armature is $14\frac{1}{2}$ lbs., which brings the weight up to a total of $57\frac{1}{2}$ lbs. The dynamo, complete, weighs 784 lbs. and gives at 1,000 revolutions 80 ampères at a difference of potential of 65 volts or 5,200 watts. This is at the rate of 6·64 watts nearly per lb. of material used.

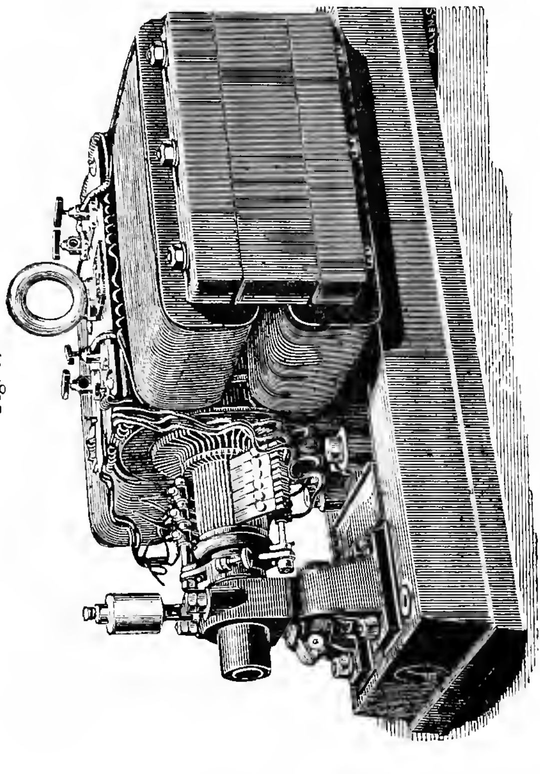
Fig. 86.



The Crompton Dynamo, manufactured by Messrs. R. E. Crompton and Co., is shown in Figs. 86 and 87. The armature of this machine is built up of thin charcoal iron washers about $\frac{1}{25}$ of an inch thick, which are insulated from each other by every alternate one being coated on both sides with Stannic paint. On the inner circumference of the washers are cut, equidistant from each other, three dove-tailed notches, Fig 86. These form, when the washers are laid together, three longitudinal dove-tail grooves running from end to end along the interior of the core. In the spindle are cut equidistant

from each other three deep grooves, which come opposite the grooves in the core; and lying radially along the whole length of the armature, dove-tailed one side into

Fig. 87.



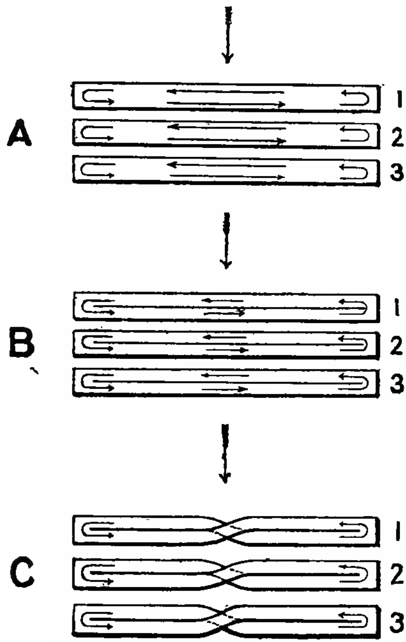
the grooves in the core and the other into those in the spindle, are strong phosphor-bronze plates by which the power is transmitted from the spindle to the core. By interposing several fibre distance pieces, which keep the washers apart, the armature core is

virtually converted into a number of comparatively narrow rings between which air can pass from the interior to the exterior to cool the core and conductors. The armature is ring-wound, the field-magnets being of wrought-iron and of the double horse-shoe type. The machine illustrated is designed for coupling direct to a high-speed engine mounted on the same bed-plate, but which is omitted in the drawing. One end of the spindle has a solid flange-coupling for connection to the engine. The magnets are supported on the cast-iron bed by gun-metal chairs. The following particulars of a similar machine are given by the *Engineer:* core of armature, 12 in. diameter, 2½ in. deep and 28 in. long; air space between core and pole-pieces, ·47 in.; core of field-magnets, 4½ in. thick by 24 in. wide; conductor on armature, 300 mils. by 180 mils. wound over the core in 96 turns; resistance of armature, ·021 ohm. The machine is intended for a current of 200 amps. at a difference of potential of 110 volts; speed 450 revolutions per minute.

Recently Messrs. Crompton have devised a new method of winding armatures, having in view the prevention of Foucault currents where copper bars are necessary for the safe carrying of the current. If the angular width of the conductor on the exterior of the armature is such that the density of force lines is unequal all over it, there are generated Foucault currents which pass in opposite directions along the two halves of the bar *A*, Fig. 88. Making the bars in two pieces, *B*, does not help us, as, being parted in the middle, the current is still free to flow in the direction of the arrows or along the two halves as before. But if the bar is made in two and the two halves crossed over as in *C*, the resulting current is *nil*, for the electromotive forces tending to produce Foucault cur-

rents oppose each other. In Messrs. Crompton's armatures for large currents, one half of the bar dips under in the middle to cross over the other half, and by these means Foucault currents in the conductors are greatly

Fig. 88.

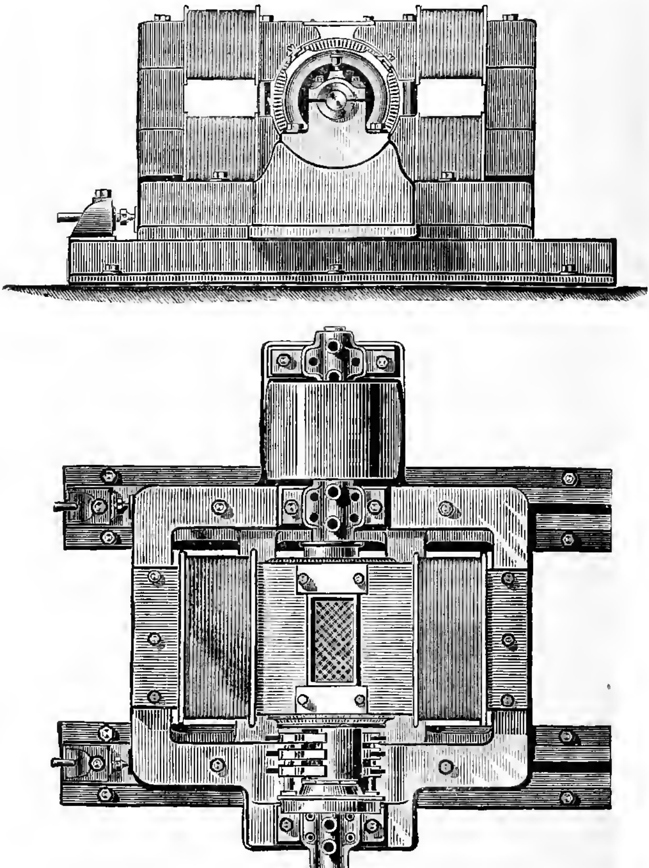


reduced. A further moral may be pointed. When armature conductors consist of a number of small wires laid together, if Foucault currents are to be avoided they should be stranded and not simply laid side by side.

The Elwell-Parker Dynamo is shown in Fig. 89. It belongs to the single magnet type, having four poles, as shown in Fig. 60. Its armature, of the ring type, has

a core consisting of iron wire coiled direct upon two sets of gun-metal supporting arms. The conductor is wound

Fig. 89.



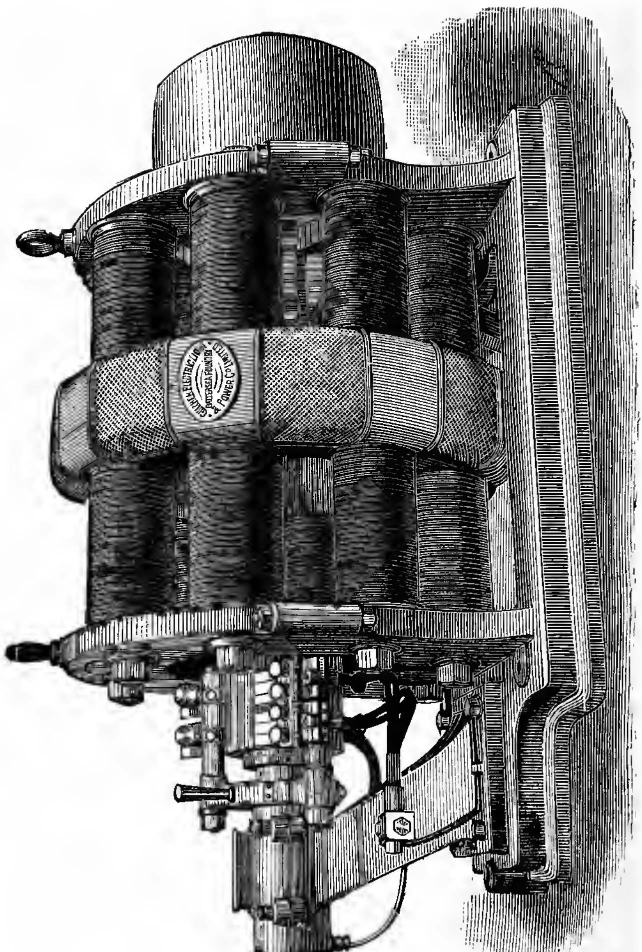
one layer deep, on the exterior, and is connected up in the usual fashion to a Gramme collector, the bars of which

are insulated with mica. The magnets are of wrought-iron, and are mounted on a strong cast-iron bedplate, which also carries the bearings for the spindle.

The machine illustrated is compound wound and has a capacity of 35 units, generating at a speed of 500 revolutions per minute, 350 amperes at a difference of potential of 102 volts. The resistance of the armature is ·01 ohm, that of the series coil ·0017 ohm, and that of the shunt 17·3 ohms. The loss in the series-coil is $350 \times {\cdot}0017 = {\cdot}5950$ volts. The shunt, being coupled up between the brushes, has flowing in it a current of $\frac{102{\cdot}595}{17{\cdot}3} = 5{\cdot}93$ amperes nearly. The total energy converted is 37,741 watts, of which 2,041 are absorbed internally, leaving 35,700 available for lighting purposes. The electrical efficiency is about 94·6 per cent. The overall dimensions of the machine are height, 2 ft. 7 in.; length, 5 ft. 6 in.; width, 4 ft. 4 in.

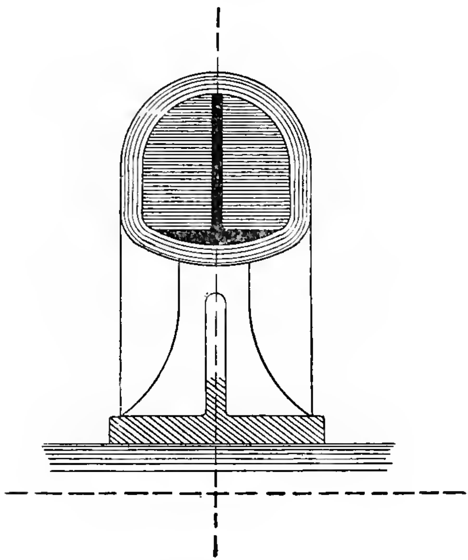
The Gülcher Multipolar Dynamo, shown in Fig. 90 and manufactured by the Gülcher Company, is a machine with a history. Coming to England in crude form with an armature-core, constructed mostly of wood, Fig. 33, since its first appearance it has been completely remodelled by English electricians. After passing through many changes it seems that finality has been reached in the form of machine illustrated, which is of the latest design. It is of the double magnet type and has 8 poles. The magnet cores are of wrought-iron on which are mounted cast-iron pole-pieces, as shown. The armature is shown in section in Fig. 91 and consists of a gun-metal wheel casting with a $\perp$ rim, on which are coiled, one on each side of the centre rib, two continuous ribbons of soft iron, the successive convolutions being separated from each other by asbestos paper wound along with the ribbons.

Fig. 90.



The armature is turned up true and the outside rounded before the conductor is coiled on, the object of the rounding being to make sure that all the lines of force enter the armature by the edge of the ribbon, the generation of Foucault currents being thus avoided. The conductor is generally wound on the armature in one or two layers;

Fig. 91.

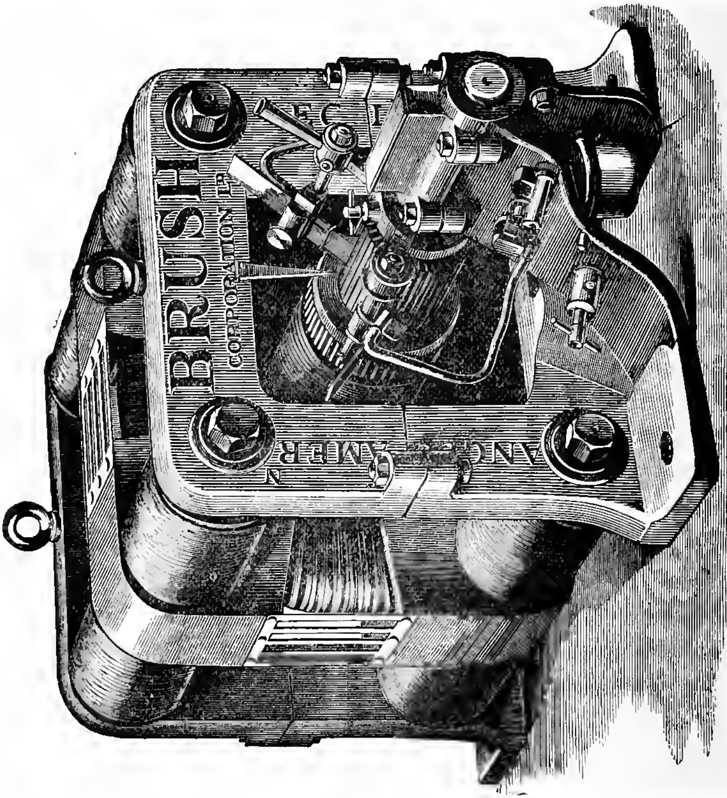


and an additional advantage of the semi-circular section lies in the fact that there is required less length of wire per volt than if the section is rectangular.

The Victoria Dynamo, made by the Anglo-American Brush Electric Light Corporation, is shown in Figs. 92 and 93. Like the machine last described it belongs to the double-magnet type, and may have four, six or eight poles according to the output required. Some years ago

the makers, in order to meet the demand which had arisen for dynamos suitable for incandescence lighting, took up

Fig. 92.



the manufacture of the Schuckert machine, and from that, by a long series of progressive steps, has been evolved the "Victoria" dynamo. When made according to the Schuckert pattern, it was found that machines wound for

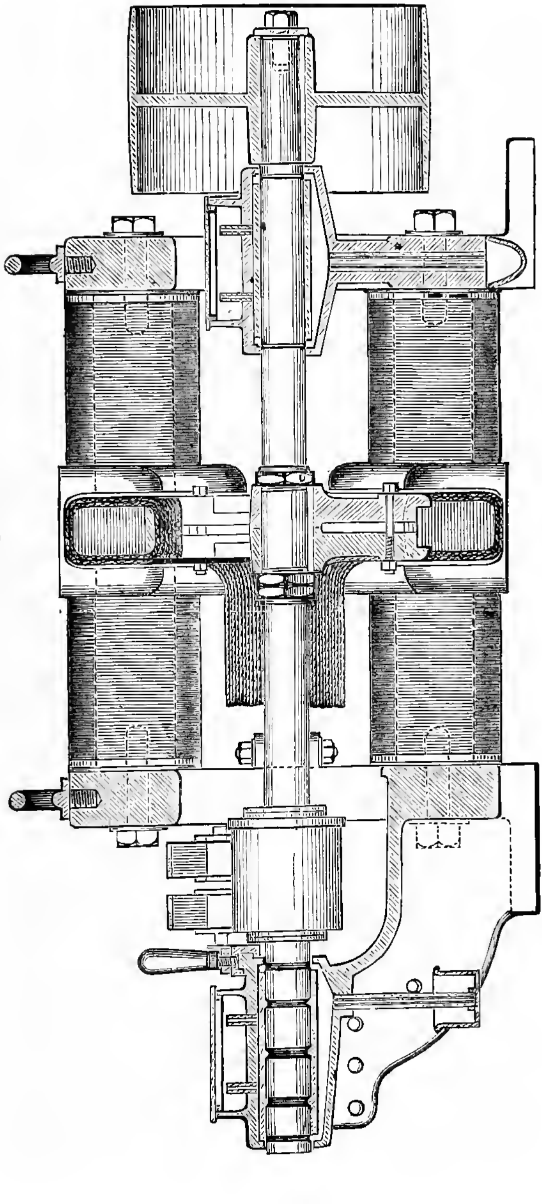


Fig. 93.

incandescence lighting evinced the same tendency to sparking at the brushes as did those wound for arc lighting. Imagining that the polar slabs, Fig. 32, might have something to do with this, they were gradually cut down until the pole pieces had an angular width about equal to twice the diameter of the magnet cores. By narrowing down the pole-pieces and giving them a somewhat different shape,

Fig. 95.

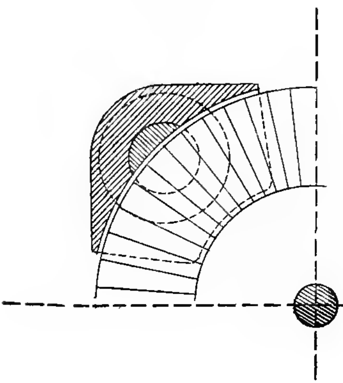


Fig. 94.

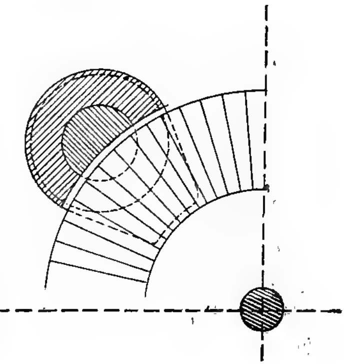


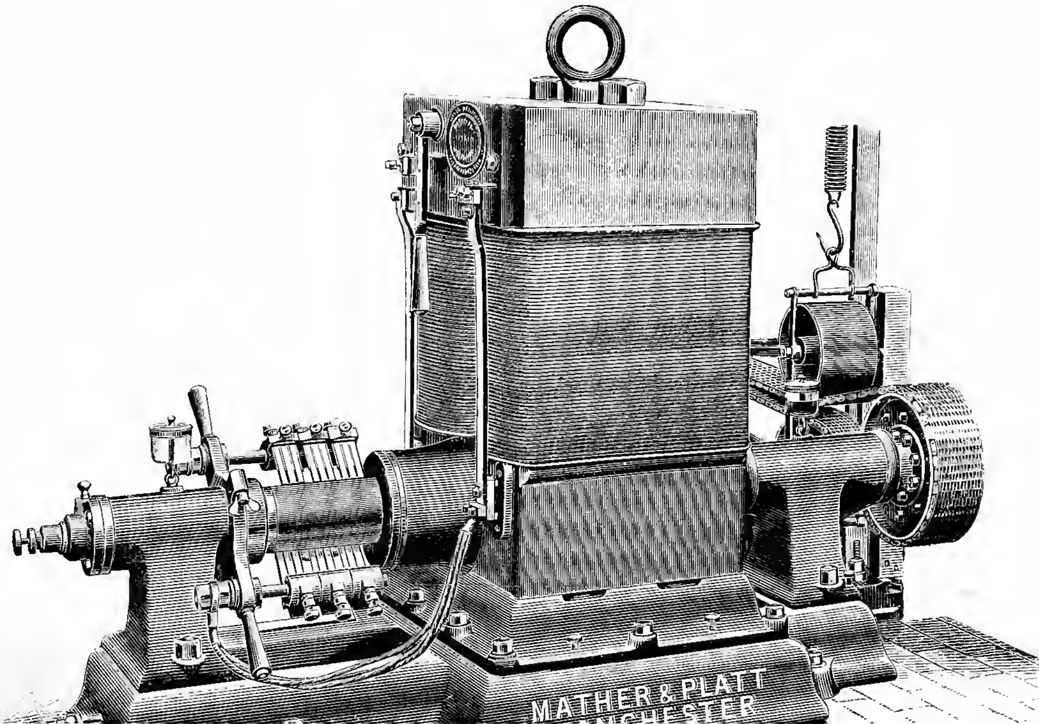
Fig. 94, the sparking was made to disappear, and as a farther result there was found room round the armature for four poles instead of two. By this modification the capacity of the armature and output of the machine at the same speed were doubled. At one time the sparking was thought to be incidental to a great angular width of pole-piece. This of course is not the case, for in disc machines, as in others, pole-pieces embracing a large proportion of the armature circumference are perfectly consistent with absence from sparking if the proper configuration is given to them. This has been proved by the

Corporation in their recent practice. In their later machines, the pole-pieces instead of having the shape shown in Fig. 94 have been extended as in Fig. 95, a decided advantage having been gained by the reduction thus obtained in the resistance of the magnetic circuit. More iron has been introduced into the field-magnets and armatures of recently constructed machines, the area of the armature core having been increased relatively to the field-magnets, and made of greater width relatively to its depth than was at one time the practice. Independently of the number of poles, the equi-potential strips of the collectors in all the machines are cross connected so that only two brushes are required. A four-pole compound machine weighing $13\frac{1}{2}$ cwts., of the type shown in Fig. 92, gives, when running at 800 revolutions per minute, a current of 150 amperes, at a difference of potential of 75 volts. The external diameter of the armature is 21 inches, and the core consists of a ring of wrought iron $\frac{1}{2}$ inch thick, upon which is coiled a $2\frac{3}{8}$ inch soft iron ribbon of No. 30, B. W. G. to a depth of $3\frac{5}{16}$ inch. The convolutions are separated by paper, and the area of iron in the cross section is 7·8 square inches. In order to reduce the waste from eddy currents, the core has cut in it a few radial grooves from the exterior a short distance inwards, which divides the outside turns of ribbon into a number of comparatively narrow strips. The armature has 360 convolutions of 165 mils. wire connected up in 60 sections and wound two layers thick. The resistance of the armature is ·0106 ohm, and the wire has a current-density of 1,800 amperes per square inch. The field-magnets have wrought iron cores $3\frac{3}{4}$ inches diameter, on which are shrunk the cast-iron pole-pieces. The out-put of the machine at the speed given is 31·4 watts per lb. of

copper, or 7·3 watts per lb. of material used in its construction. The cooling surface of the magnet coils is 1·61 inches per watt expended in them.

The Edison-Hopkinson Dynamo, manufactured by Messrs. Mather and Platt, is a modern development of the original Edison machine, due to Dr. J. Hopkinson. In the original machines, Fig. 47, the magnets consisted of a number of separate cores connected to one common pole-piece, this construction being common to the smaller machines for isolated lighting, as well as to those intended for central stations. One of the most important improvements consisted in substituting, for these multiple cores, one heavy core of large section and of much shorter length, whereby the cross section of iron which could be employed for an armature of given length was greatly increased, the length of wire required for excitement being at the same time greatly reduced. In the original machines the iron discs, of which the armature-core is built up, were held together by uninsulated bolts passing right through all the plates, the result of this being a heavy loss due to the generating of eddy currents. In the Edison-Hopkinson machine, Fig. 96, these bolts are omitted and the plates are held together by nuts screwed on to the spindle itself, which thus serves as a bolt. Concomitantly with the increase in the section of the magnets, the armature section has been increased, the distance between the steel spindle and the inner edges of the discs being merely sufficient to prevent any serious magnetisation of the former. The area of the armature core is rather more than ·8 of the cross section of the magnets. The final results due to these improvements are: (*a*), the reduction of the resistance of the magnetic circuit and an intensely strong field created by a minimum

Fig. 96.—(*To face page* 296.)



expenditure of energy; (*b*), due to the strong field, a less length of wire per volt in the armature and a correspondingly reduced resistance. In the Fig. is shown a 10 in. long armature, shunt-wound machine, which, at a speed of 750 revolutions per minute, generates a current of 320 amperes at a difference of potential of 105 volts. The armature is built up of about 1,000 charcoal iron discs, $9\frac{11}{16}$ in. diameter, separated by sheets of thin paper. It is wound with 40 complete turns of a conductor consisting of 16 wires in parallel, 69 mils. in diameter. The collector has 40 bars of drawn copper insulated with mica, the connections to the coils being made by gold-plated spoons to ensure good contact, while, at the same time, facilitating repairs. The armature resistance is ·009947 ohm. at 13·5° C., and the weight of wire wound on it is 55 lbs. The magnets and pole-pieces are of wrought-iron, the cores measuring 18 in. in length by $9\frac{1}{2}$ in. in thickness, and having a cross sectional area of 171 square in. Each limb is 24 ins. long, and has wound on it 1,544 turns in eight layers of 95 mils. wire. There are 205 lbs. on the magnets, and the resistance is 16·93 ohms. Electrical efficiency, 95 per cent. Weight of machine, $51\frac{1}{4}$ cwts. Weight of armature, $5\frac{1}{2}$ cwts. These dynamos have been tested by coupling together, as described on page 274, part of the dynamometer gear employed being shown in the Fig. When thus coupled they gave for both generator and motor a commercial efficiency of about 93 per cent.

The Edison Dynamo.* The manufacturers of the Edison machine in America have been led to modify their designs very considerably, their latest dynamos, Fig. 97,

* The author is indebted for the illustration to the proprietors of *Industries.*

closely resembling those of the Edison-Hopkinson type. The wrought-iron magnets are of circular form and have been made shorter and thicker than was at one time the practice. The pole-pieces are of cast-iron and are swelled out externally to reduce the weight, while at the same time ensuring a sufficiently large area for the lines of force to pass through without throttling. The illustration clearly indicates the changes which have been made, the machine shown giving at 750 revolutions 400 amperes at a difference of potential of 113 volts. The armature resistance is ·0072 ohm.

The Weston Dynamo is another machine of the drum-wound type which has undergone in recent times considerable modification. Shown as originally designed in Fig. 42, the improvements effected have been of a similar character to those described in connection with the Edison-Hopkinson machine. The magnet cores have been made more massive and the pole-pieces and yokes much heavier. More iron has been introduced into the armature core, there being left in the centre of the toothed discs an opening only large enough to admit the spindle. The shunt-wound machines, on account of their low armature resistance and small number of convolutions, are said to be almost self-regulating, a machine for 100 twenty candle-power lamps having only 24 complete turns on its armature connected up to a 24-part collector.

The Chamberlain-Hookham Dynamo, a machine of recent date, is illustrated in Fig. 98. It belongs to the double-magnet drum-wound type, having an armature core built up of soft iron toothed plates separated by paper. The illustration shows a 10 unit machine, giving, at a speed of 1,250 revolutions per minute, a current of 175 amperes at a difference of potential of 59 volts.

Fig. 97.—(*To face page* 298.)

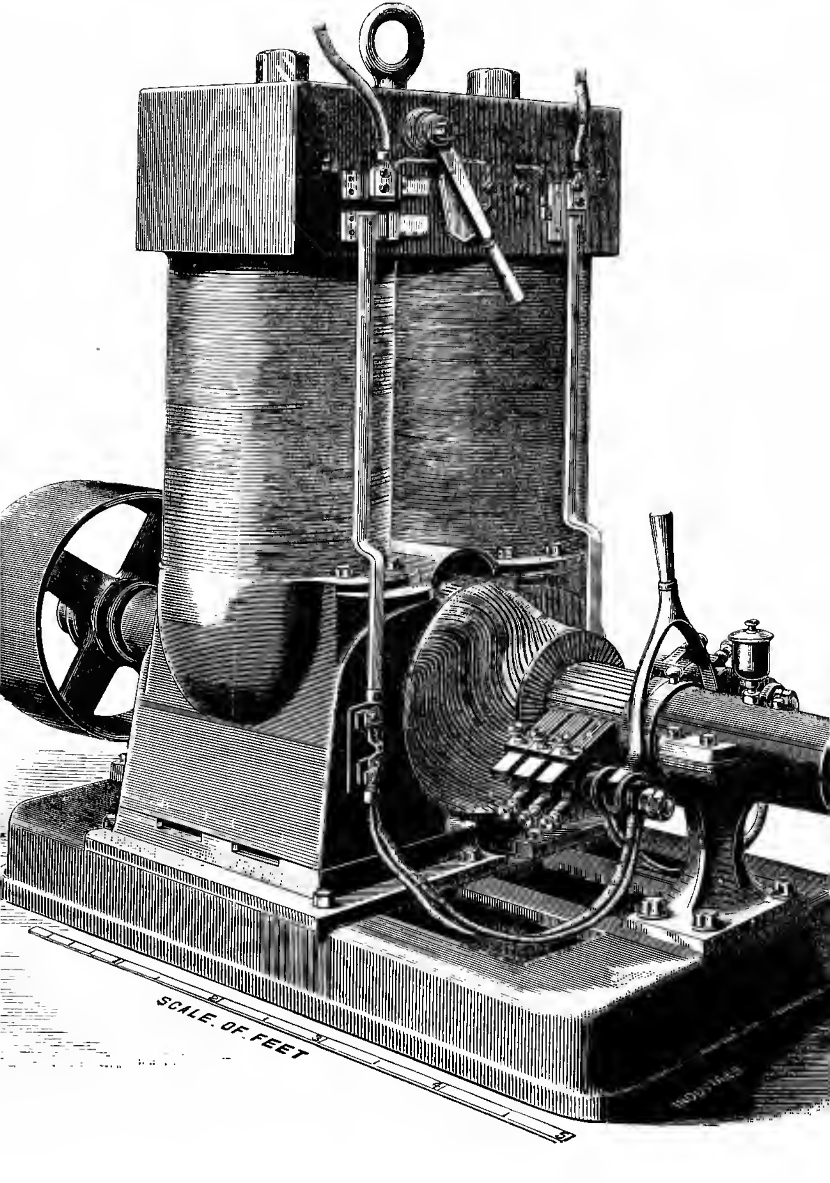
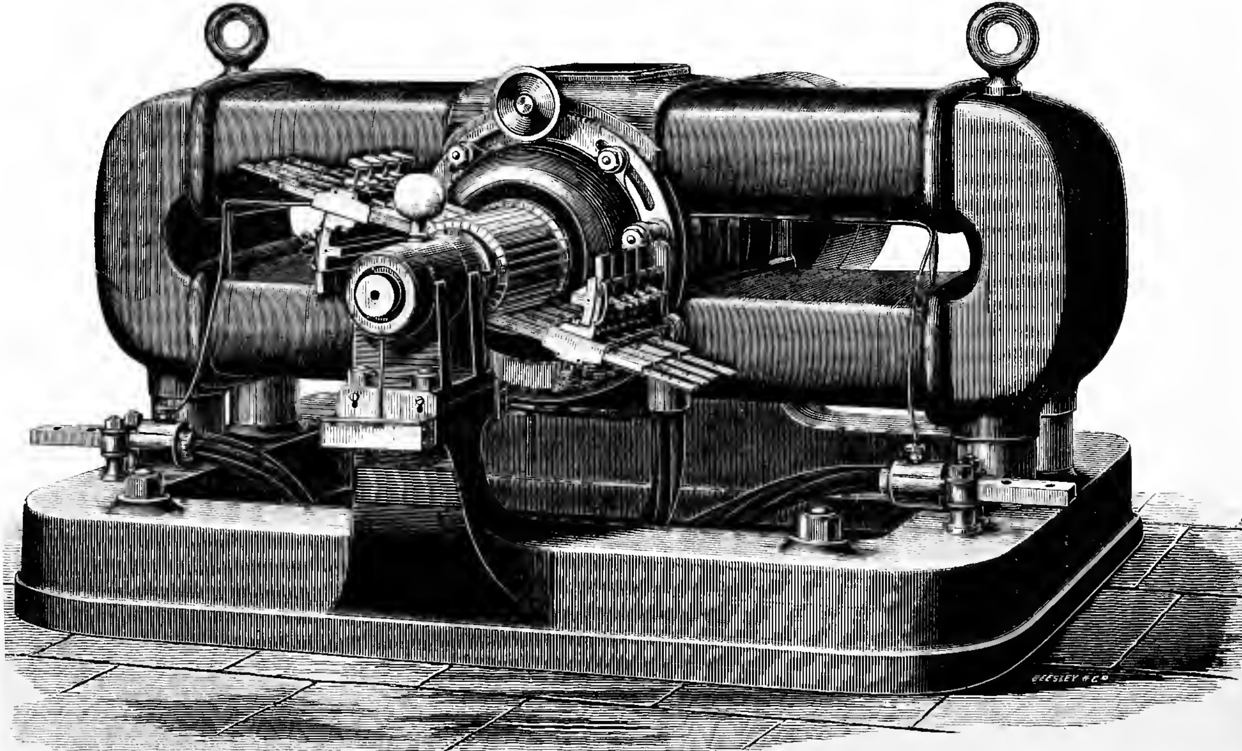


Fig. 98.—(*To face page* 299.)

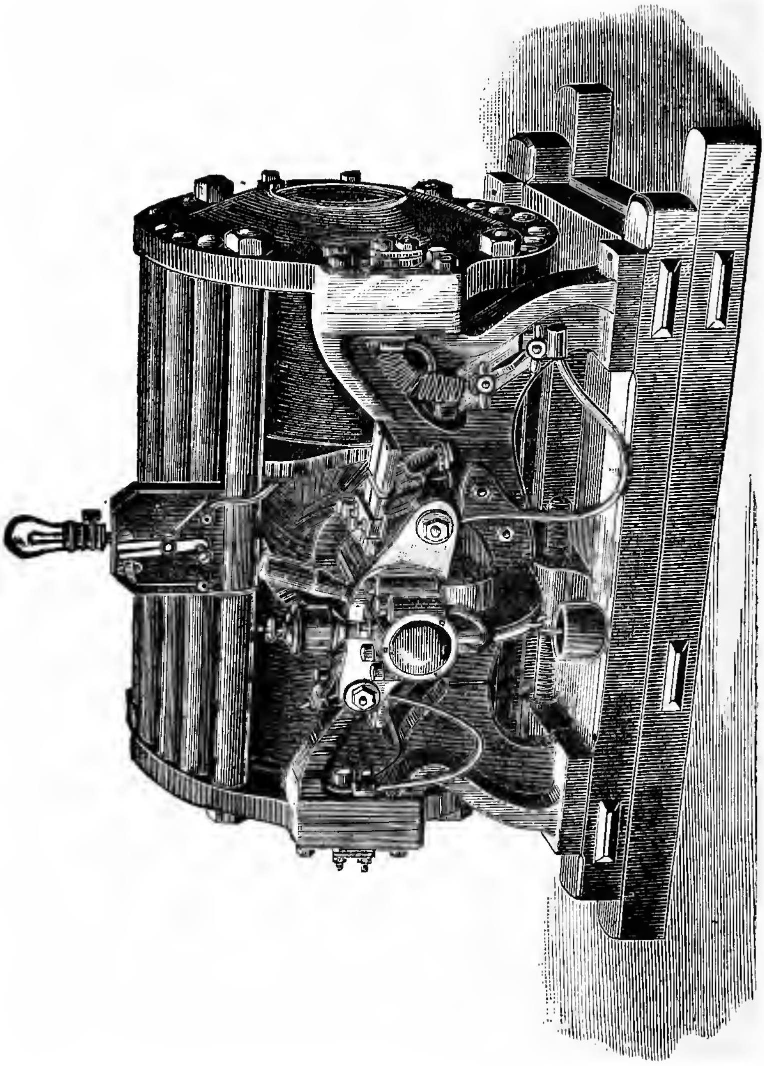


The armature is $7\frac{1}{4}$ in. diameter by 9 in. long, and the sum of the areas of all the projections at any time under a pole-piece is equal to the cross section of the armature core. There are on the armature 41 complete turns of two rectangular wires in parallel, which have, when connected up, a resistance, hot, of ·007 ohm. The magnet cores are of wrought-iron, over which are cast the yokes and pole-pieces. The yokes are in two parts, bolted together, the magnetising coils being wound directly on the wrought-iron cores. The brush adjustment, by a pinion and toothed segment cut in the brush-cradle, is clearly shown in the engraving. The following particulars of a 25 unit machine of similar type are given in *Industries* of Oct. 1, 1886. Armature: length, 13 in.; diameter, 10 in.; cross section of iron-core, reckoning from base of slots, 30 square in.: winding 35 complete turns of 12 wires in parallel in two layers, inside layer of 104 mils., outside layer of 116 mils. Resistance, hot, ·003 ohm. The field-magnets have a cross section of 42 square in. and are shunt-wound with 2,856 turns of 109 mils. wire; resistance, hot, 8 ohms.; current through shunt, 7·13 amperes. At a speed of 900 revolutions per minute, a current of 450 amperes is generated at a difference of potential of 57 volts, the total weight of the machine being 25 cwts. This is at the rate of 9·16 watts for each lb. of material used.

The Thomson-Houston Incandescence Dynamo is shown in Fig. 99*. The machine is of very recent design, its field-magnets resembling those of the arc machine described on page 262. The spheroidal armature is retained, being in this machine built up of annealed iron

* The Author is indebted to the Proprietors of *The Electrical Review* for the illustration.

Fig. 99.



rings carried by hubs on the shaft. For the open-coil has been substituted the ordinary closed-coil winding, the sections being connected up to a several part collector. The field-magnets are more massive than in the arc dynamo and are compound-wound, the series-coil being situated in front of the magnet cores and at a certain angle to the magnetic axis of the latter in order to compensate distortion of field due to the current flowing in the armature. Electrical details are not yet to hand, but the machine appears to occupy the position of being the most costly to manufacture and the most awkward to repair. Employed for incandescence lighting, it may, not unjustly, be regarded as illustrating the persistence of a type when the circumstances which led to its development have ceased to exist.

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